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J. W. POWELL, DIRECTOR

THE

PRESENT CONDITION OF KNOWLEDGE

OF THE

GEOLOGY OF TEXAS

BY

ROBERT T. HILL

WASHINGTON

GOVERNMENT PRINTING OFFICE

1887

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PREFATORY NOTE.

Geologic investigation in Texas has been fragmentary and unsatisfactory for many reasons: hostile Indians till recently ravaged the western half of the State; the civil war suspended the work of a comprehensive geological survey inaugurated under the State legislation of 1858, and that survey resuscitated and a later organization both came to naught. The U. S. Geological Survey has extended its operations into the State too recently to increase greatly the published knowledge of the geology of Texas.

To study intelligently the geology of this State it is important that a digest of such material as has been already published should be made. The present bulletin comprises an historical statement of such scientific work as has added to available knowledge of the topography and the paleontology as well as the geology of the State, but it is not intended to include unpublished knowledge gained by my residence and study in the State, except as that knowledge modifies comments on conclusions already in print. Other publications will embody such matter in due time. The present work does not extend the record beyond January 1, 1886.

PRESENT KNOWLEDGE OF THE GEOLOGY OF TEXAS.

By Robert T. Hill.

I. HISTORICAL STATEMENT RESPECTING GEOLOGIC INVESTIGATION.

KNOWLEDGE AT THE BEGINNING OF THIS CENTURY.

Geology as a distinct science is so recent that we should not expect to find specific information upon that subject in early records; but geologic facts worthy of our attention are sometimes discernible in the descriptions of local geography and natural history given by intelligent travelers. The most complete and trustworthy compilation of the early Spanish, French, and Mexican authorities, with other historical data, is to be found in a work prepared by William Kennedy,[1] which is preferable to many later histories because of the scholarly and unprejudiced manner in which it was written.

The knowledge derived from previous authorities was embodied in the works of Baron Friedrich Heinrich Alexander von Humboldt, who visited Spanish America in the employ of Spain in the years 1799–1804, collecting all available information.

Although his studies extended into this century, his writings may justly be considered a correct statement of the geologic and geographic knowledge at the opening of the century. He first attempted to represent the principal features of the region on a map which accompanies the Voyage au régions équinoctiales du Nouveau Continent, par A. de Humboldt et A. Bonpland. His physical observations upon the mountains and plains, his numerous measurements of the region of the Upper Rio Grande, and his formulation of meteorologic laws concerning that region were all valuable, though indirect, contributions to our knowledge of Texas, which it seems he did not visit personally. A glance at his map is sufficient to show that the conception he possessed of this region, although the best of his time, was vague and indefinite. The sources and the courses of the rivers are incorrectly delineated. Streams having their sources in the eastern portion of the plains are represented as originating in lakes, an error probably arising from the fact that in the vicinity of San Antonio de Bexar, which at that time was the nucleus of Spanish settlement, the water courses arise from outbursting springs which usually expand into extensive pools of water. These phenomena

[1] Texas: The Rise, Progress, and Prospects of the Republic of Texas. By William Kennedy, esq. In two volumes. London, 1841. 8°.

are purely local, however, and the streams of Texas as a general rule are but the seaward continuation of long arroyos usually dry in the beginning of their courses.[1] The latitude and the longitude of all interior places are incorrectly given by many degrees.

The delineation of the old Spanish roads across Texas is also a feature of Baron von Humboldt's map indirectly bearing upon the geographic and geologic knowledge of the last century, for they indicate the extent of the country that came under the observation of the travelers of that time. They also indicate that the Spanish inhabitants were familiar with some of the results of one of the characteristic geologic features of Texas, for a road leads to the Paleozoic region of the San Saba, where it is certain that extensive explorations for minerals and some mining operations were conducted by them.[2]

ANGLO-AMERICAN ADVENTURERS AND COLONISTS.

The general exclusion of foreigners from the region while it was a province of the viceroyalty of New Spain, at the close of the last and in the beginning of the present century, tended to prevent exploration similar to that then going on in the United States, where the war of the Revolution had hardly closed before an epoch of scientific experiment and exploration was inaugurated. Before two decades of the present century had passed, governmental and private expeditions had explored a great portion of the territory of the United States as then defined. According to William Kennedy, who occupied a diplomatic position at a later period in Mexico,[3] "it will readily be inferred that the success of the United States in achieving their independence and the rapid growth of the federation were not regarded with indifference by the intolerant and suspicious government of Spain, whose step-dame treatment of its transatlantic dependencies supplied abundant cause of disaffection. Lest the dreaded principles of the North American Republic should contaminate the populous districts of Mexico, it became more than ever necessary to guard against the intrusion of foreigners through Texas. The feelings entertained by the Spanish authorities were manifested in a favorite saying of a captain general of the eastern internal provinces * * * that, had he the power, he would prevent the birds from flying across the boundary between Texas and the United

[1] Attention is here called to the misapplication of the old Spanish names by American travelers of this century, to be seen on comparison of any recent map with Humboldt's. It may have been the natural result of the confusing manner in which the Spaniards applied the terms "muddy" and "red" to all streams within this region that we have a great multiplication of "Red," "Colorado," "Pecos," and "Puercos" rivers throughout the Southwest.

[2] Traditions of these old Spanish mines still cause the people of Central Texas to spend much time in endeavoring to find precious minerals in the various formations of that region.

[3] Texas: The Rise, Progress, and Prospects of the Republic of Texas. By William Kennedy, esq. In two volumes. Vol. I, p. 236. London, 1841.

States. Perpetual imprisonment, at least, awaited the unlucky wanderer who was caught on the forbidden soil without the protection of a special license." It is not to be understood, however, that the Spanish government was not in its way a most liberal patron of natural science; its encouragement of Humboldt affords sufficient evidence of this. It must be remembered, however, that the time of which we write (1790–1810) was one of peculiar relations to scientific work in New Spain. Not only did the Spanish government, after its manner, encourage science, but, according to the laws of the Indies, which governed the supreme courts of Spanish America, permission to travel was procurable only upon condition that its object was research in natural history. The fact must not be forgotten, on the other hand, that the diluvian theory of that day had not yet met disastrous defeat from the stratigraphists and that the church that governed New Spain still directed and defined the scope of scientific exploration within its territory, and infidel observations were considered no more desirable by the clergy than were Anglo-American explorations by the state. These, also, were the last days of Spain's tottering rule in Mexico, and soon the revolution that ultimately freed the latter country from her power formed another serious obstacle to investigations of Spanish America by citizens of the United States.

PHILIP NOLAN.

Notwithstanding the numerous difficulties, an irrepressible spirit of adventure led many citizens of the United States into Spanish territory. To one of these we are indebted for the first Anglo-American contribution to the knowledge of the geography of Texas. Philip Nolan, a frontier trader, an Irishman by birth, in 1797 made a trading expedition into the Province of Texas from Natchez, Miss., at that time the outfitting town of the southwestern border. He was a shrewd observer and recorded his impressions of the country, which, on his return to Natchez, he published in a small work accompanied by a topographic map, his being the first description of Texas by an actual observer printed in the United States. The results were trifling, the map was incorrect and restricted, and, moreover, the book is practically out of existence. Upon returning to Texas, Nolan paid the penalty of death for his offense against Spanish jealousy, being shot while resisting capture March 21, 1801.

Others soon followed Nolan, notwithstanding the watchfulness of the Spaniards. None of these, however, except one or two military explorers, referred to hereafter, left written reports of their labors.

AMERICAN COLONIZATION PERIOD.

The Anglo-American adventurers who had so assiduously penetrated the Spanish possessions brought back to the United States many reports of the fertility of the region. The Spaniards cared little for the land

and were desirous of securing actual settlers. The combination of these two facts resulted in that unique epoch of the history of Texas now generally spoken of as the period of colonization under the empresario grants,[1] 1820–1834, during which time Anglo-American settlers gained a firm foothold in what had hitherto been the jealously guarded territory of Spain. During this period Mexico threw off the Spanish yoke, which gave increased impetus to Anglo-American settlement of Texas.

The Spanish system of empresario or contract grants of land was as follows: The authorities gave large tracts to parties or companies upon condition that they would locate upon them a certain number of colonists. The metes and bounds of these grants were not defined by actual surveys, but by certain vaguely understood natural boundaries, such as the streams and mountains. This system of land grants obviated the immediate necessity for governmental topographic surveys and permitted the location of lines to be intrusted to individuals, which much confused the topographic knowledge of the state.

Stephen F. Austin, who on the death of his father, Moses Austin, inherited the latter's concessions, also succeeded him as leader of a body of immigrants from Missouri, and conducted the first colony from the United States to Texas, at the time (1821) a portion of Mexico. He was a man of more than ordinary intelligence, and, pursuing a different course from that adopted by most of the men who accepted the empresario grants, before locating his colony he personally explored the region granted him. He made a practical contribution to the knowledge of the country by means of many articles in the newspapers of the Northern United States and he compiled a map of Texas that was far superior to any that had previously been published.

Mary Austin Holley, in 1833, wrote a small work upon Texas, which gave popular descriptions of its natural history and topography, but was not of marked value to science.

The Texan war of independence (1834–1836), the Texan Republic (1836–1845), and the war of the United States with Mexico (1846) marked years unproductive of important Anglo-American contributions to scientific knowledge of Texas, although a map was issued by Messrs. Hunt and Randall, of the Texas land office, in 1835. They also published a small guide to Texas. The Santa Fé expedition took place during this time, but its annals contain nothing of definite scientific value.[2]

EUROPEAN INVESTIGATORS.

We owe to foreign investigators the greater portion of the knowledge we now possess of the geologic features of Texas. The writings of Baron von Humboldt have already been mentioned. During the political

[1] See various histories of Texas: Thrall, Kennedy, Foote, and others.

[2] See Narrative of the Texan Santa Fé Expedition. By George Wilkins Kendall. Harper Brothers, New York, 1850.

troubles incident to the war of Texan independence and its accompanying excitement several distinguished foreigners visited the region, and to them we owe not only the first purely scientific information but also by far the most satisfactory geologic treatise yet published regarding Texas.

WILLIAM KENNEDY.

The British government in the year 1838 sent William Kennedy upon a diplomatic mission to the young Republic of Texas. This gentleman, in addition to a most liberal education, possessed very keen powers of observation, which had been greatly sharpened by years of cosmopolitan travel. While in Texas he closely studied the topography, natural history, and geology of the country, and upon his return to England he published, in 1841, the first intelligent statement of the natural and political history of Texas and the first scientific description of the country based upon personal observation.

Considering the time and the conditions under which this work was written, too much praise cannot be bestowed upon it. Its title page[1] makes no allusion to the valuable scientific matter it contains, and to this alone can I attribute the fact that the book is so little known to scientific men. Book I of Volume I, consisting of 200 octavo pages, is entirely devoted to the "Geography, natural history, and topography of Texas," and contains much of the knowledge set forth by later writers, most of whom, strange to say, have not mentioned this fountain head of their information.[2]

Although the contribution was small in volume and general in character, it justly deserves the following credit:

(1) It gives the first carefully compiled topographic map of the region. This map represents authentically the state of geographic knowledge of Texas in the year 1839 and is far superior in points of detail, accuracy, and completeness to any of the maps that had been compiled previously or that appeared at about the same period.[3]

(2) It presents the first geologic description of the country. This description, although short and untechnical, outlines much of what later workers have more carefully described and published, excepting that of a purely paleontologic nature.

(3) It has the first intelligent description of the natural history of the country.

Mr. Kennedy gives first an account of the geographic extent and boundaries of the country and its natural divisions. Stating the "remarkable contrast between the border sections and the lands of the interior," he next deals with the seacoast peculiar to this region, and

[1] Texas: The Rise, Progress, and Prospects of the Republic of Texas. By William Kennedy, esq. In two volumes. London, 1841.

[2] Dr. Roemer is a notable exception.

[3] Hunt and Randall's and Scherpf's maps appeared about the same time as this.

he notes the "alluvial accumulations and encroachments of the land on the gulf." He also gives a general hydrographic view of the State and a comparison of the rivers on the eastern side with those on the western side of the Rocky Mountains, describing many physical features that have now become the common basis of all descriptions.

He devotes an entire chapter to the peculiar climatology of Texas, a subject of great importance in the superficial geology of the State, and one the peculiarities of which Mr. Kennedy described most ably, considering the state of knowledge at the time he wrote. The zoölogic and botanic resources are given, and he was the first to describe the "cross timbers," a unique feature of the country which still remains an unsolved geologic problem.

Mr. Kennedy in describing the general features of the country notices the great extent of the Cretaceous formation in Texas and mentions for the first time in print the older Paleozoic strata. He speaks of fossils, of the various minerals, of "peculiar species of stone," &c. The appearance of asphaltum is mentioned, as well as the superabundant petrified woods of Texas. Mr. Kennedy also gives us the most complete and trustworthy enumeration of the early Spanish, French, and Mexican explorations in Texas.

G. A. SCHERPF.

An emigration movement in Germany gave an impulse at this period to another series of investigations. We probably owe the first German description of Texas to G. A. Scherpf, who in 1841 published a work[1] accompanied by two maps, one being a map of the country to the Pacific Ocean and the other a map of Texas, compiled from the material of the General Land Office of the Republic, in 1839, by Richard S. Hunt and Jesse F. Randall.

The work, as indicated by Dr. Ferd. Roemer, is valuable from the fact that it is based upon the personal observations of the author during a long residence in the country, though Dr. Roemer generally found through observations of the region here and there that Scherpf had painted his picture in too glowing colors.

PRINCE CARL SOLMS-BRAUNFELS.

In connection with the Mainz-Verein, a company organized to facilitate German emigration to Texas, much was published concerning the country. The patrons of the movement were German noblemen, who organized the union at Mayence in the spring of 1844.

In 1846 Prince Carl Solms-Braunfels, the chief promoter of the union and at that time its resident agent in Texas, published and distributed

[1] Entstehungsgeschichte und gegenwärtiger Zustand des neuen, unabhängigen, amerikanischen Staates Texas. Ein Beitrag zur Geschichte, Statistik und Geographie *dieses Jahrhunderts.* Im Lande selbst gesammelt von G. A. Scherpf. Augsburg, 1841. *8°, pp. vi, 154, 2 maps.*

throughout Germany a handbook for emigrants to Texas, accompanied by two maps.[1]

VICTOR BRACHT.

Victor Bracht added to the German works of this period one[2] describing Texas in the year 1848. It contained a few references to the topography and the natural history of the State, but it was mainly an enthusiastic appeal for German emigration.

FERDINAND ROEMER.

In 1845 Dr. Ferdinand Roemer, the distinguished geologist and paleontologist, visited Texas to make a scientific study of its adaptation to German settlement. Dr. Roemer was in the State from December, 1845, the month of annexation, until April, 1847. His labors resulted in the most valuable contributions to the knowledge of the geology of Texas that have yet been made. These were published as follows:[3] Two preliminary papers in the American Journal of Science and Arts and two volumes in German, whose titles, given below, may be respectively translated as "Texas, with especial reference to German emigration and the physical condition of the country, based upon personal observations," Bonn, 1849, and "The Cretaceous formation of Texas and its organic remains, with a description of the Tertiary and Paleozoic strata appended," Bonn, 1852.

These works contain the first purely scientific discussions of Texas. The volume first named, as its title indicates, was chiefly written for

[1] Texas: Geschildert in Beziehung auf geographischen, socialen und übrigen Verhältnisse, mit besonderer Rücksicht auf die deutsche Colonisation. Ein Handbuch für Auswanderer nach Texas. Seinen deutschen Landsleuten gewidmet von Carl Prinzen zu Selms-Braunfels; nebst zwei Karten von Texas. Frankfurt-am-Main, 1846. 8°.

[2] Texas im Jahre 1848, nach mehrjährigen Beobachtungen dargestellt von Victor Bracht (seit 1845 Burger jenes freien Staates). Elberfel und Iserlohn, 1849, bei Büdeker. 8°.

[3] Following is a list of the writings of Dr. Ferdinand Roemer on the geology of Texas:

(1) "A Sketch of the Geology of Texas; by Dr. Ferdinand Roemer. (In a letter to the editors dated New Braunfels, German settlement on the Guadaloupe, in Western Texas, Comal County, June 12, 1846)." Am. Jour. Sci., 2d ser., Vol. II, pp. 358–365 1846.

(2) "Contributions to the Geology of Texas; by Dr. Ferdinand Roemer." Am. Jour. Sci., 2d ser., Vol. VI, pp. 21–28, 1848.

(3) Texas: Mit besonderer Rücksicht auf deutsche Auswanderung, und die physischen Verhältnisse des Landes nach eigener Beobachtung geschildert von Dr. Ferdinand Roemer. Mit einem naturwissenschaftlichen Anhange und einer topographisch-geognostischen Karte von Texas. Bonn, bei Adolph Marcus, 1849. 8°, pp. xiv, 2, 464, with map.

(4) Die Kreidebildungen von Texas und ihre organischen Einschlüsse, von Dr. Ferdinand Roemer. Mit einem die Beschreibung von Versteinerungen aus paläozoischen und tertiären Schichten enthaltenden Anhange und mit 11 von C. Hohe nach der Natur auf Stein gezeichneten Tafeln. Bonn, bei Adolph Marcus, 1852. 4°, 100 pp., with plates.

German emigrants, but its contents include much valuable scientific matter in addition to the first geologic map of Texas. This was printed in colors, indicating the superficial distribution of the formations. Although crude and imperfect, it contains all the definite information of the region then accessible and most of what has been delineated on more recent maps.

The scientific contents of this work, in addition to the above described map, are as follows:

(1) The geographic position and bounds of the State.

(2) A description of the topographic features of the country.

(3) Its general botanic and zoölogic features.

(4) Its mineral products.

(5) Bibliography of writings on Texas.

(6) Stratigraphic features of the State, including descriptions of the following formations: The diluvial and alluvial (Quaternary), the Tertiary strata, the Cretaceous strata, the older or Paleozoic strata, the Azoic [1] strata.

(7) The first contribution to the paleontology of Texas, consisting of descriptions (not figured) of the following faunas that he studied, many species of which were entirely new to science: The fossils of the Cretaceous and the fossils of the Carboniferous and Silurian strata on the San Saba River.

(8) A description by Rev. Adolph Scheele of the plants of Texas collected by Dr. Roemer.

(9) A zoölogic description of the region, giving many descriptions and localities of the radiata, articulata, mollusca, and vertebrata.

Although Mr. Kennedy had previously alluded to many of the facts here set forth, Dr. Roemer deserves the credit of developing and presenting them to the world; for, as he said at the time this publication was made, he had been unable to find a single European or American publication on the peculiar features or distribution of the geologic formations of Texas.[2] The explorations of Dr. Roemer in the western portion of the State were limited by the fact that those formations whose exploration would yield the most interesting geologic results begin where the settlements left off and where were located the hunting grounds of murderous Indian tribes.[3] So important were the geologic observations of Dr. Roemer, as announced in this volume (and a few scattering magazine articles the year before), and so minutely do they bear upon the subsequent pages of this account that it is thought desirable to give a brief résumé of the work.

(1) He outlined and discussed the age and stratigraphic conditions of the alluvial and Quaternary deposits as now generally accepted and noted the finding of fossil vertebrates[4] in many localities. He also noted the fossil exogenous woods which they contained, lamenting that their proper horizon was not known. Their occurrence with flint nodules in the detritus of the Tertiary strata he thought an indication of their Cre-

[1] Not so considered now.

[2] Texas, p. 365.

[3] Ibid., p. 366.

[4] Previously noted by Wm. M. Carpenter. See Am. Jour. Sci., 2d ser., Vol. I, p. 244.

taceous origin. He expresses the opinion that this "diluvial and alluvial" formation is composed by the sedimentation from the erosion going on in the western portion of the State.

(2) He first described the occurrence of the Eocene in Texas, at Wheelock, Caldwell County, where he found *Pleurotoma*, *Fusus*, *Turritella*, *Cerithium*, *Natica*, *Bulla*, *Dentalium*, *Cardita*, *Corbula*, *Nucula*, &c., and justly concluded that they were identical with those of the formation at Fort Claiborne, Alabama. "It is hardly to be believed," he correctly says,[1] "that this Tertiary formation is limited only to this point on the Brazos in Texas, but most probably it is part of a continuous band, as is the case in Mississippi and Alabama, extending along the foot of the Cretaceous, and only the detritus of the later alluvial formations prevents its exposure in most places."

(3) He outlined and described the Cretaceous formation of Texas.[2] "Of all the formations," said he,[3] "either eruptive or stratified, the Cretaceous formation plays by far the most important part in the geologic features of Texas."

(4) He first noted the absence of the Jurassic and the probable absence of the Triassic[4] formation from the geologic series in Texas.

(5) He first described the stratigraphic relations and the organic inclosures of the Paleozoic rocks between the Pedernales and San Saba Rivers, upon the right bank of the Colorado. This peculiar, isolated outcrop of Paleozoic strata (Potsdam of Walcott), upon the position and relations of which Mr. C. D. Walcott has lately thrown so much light, was well described by Dr. Roemer, considering the state of geologic knowledge at that time. He also noted its resemblance to a certain isolated patch of what he considered similar rocks in Missouri.

Of these rocks:

(*a*) He first recognized the Carboniferous formation, not by any lithologic peculiarity, but by its undoubted, characteristic fauna, including *Orthis umbiculatum* von Buch and *Spirifera crenistriata* Sowerby. This outcrop was the most southern exposure of the Carboniferous in Texas and Dr. Roemer was unable to explore it farther north.[5]

(*b*) He first noted the absence of the Devonian in Texas, but erroneously concluded that this formation does not extend west of the Mississippi.[6]

(*c*) He described an impure, fragmentary, semicrystalline limestone north of the Llano River, in horizontal or hardly disturbed strata, full

[1] Texas, p. 372.

[2] For details, see p. 71.

[3] Texas, p. 373.

[4] Dr. Roemer's observations did not extend westward to that portion of Texas now said by some disputants to be Jura-Trias.

[5] Innumerable allusions to "coal" are found in popular works, but most of these undoubtedly refer to the widely disseminated *true lignite* of the Cretaceous and Tertiary, which is very abundant in this portion of Texas.

[6] Texas, p. 389.

of organic remains, mostly trilobites, only one *Orthis* in addition to these having been observed.

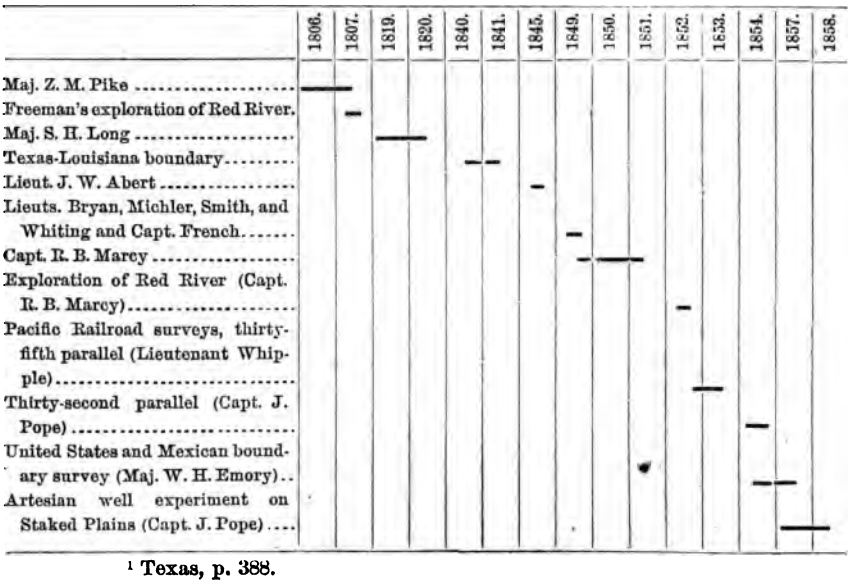
Dr. Roemer observed the same strata some forty miles distant and described several additional organic forms, including the new species *Pterocephalia Sancti Sabæ* Roemer. This he concluded[1] was Lower Silurian. He found at another place a stratum which he also considered Lower Silurian, and which he described as consisting of a firm, white, silicious limestone containing *Euomphalus Sancti Sabæ* Roemer.

(*d*) He described the character of the older crystalline rocks that underlie the Silurian (Cambrian) strata.

Dr. Roemer's celebrated monograph (Die Kreidebildungen von Texas und ihre organischen Einschlüsse) was an elucidation of the facts he had already given in his Texas. Its chief additional points are the figures of Texas fossils and the careful, accurate descriptions of the same, as well as the more detailed account of the Texas Cretaceous. The author alluded to his descriptions in the work entitled Texas as being merely diagnoses, although they far excel in accuracy and fullness many of the descriptions since published by early American paleontologists. This work is one of the most complete and satisfactory of the early contributions to the geology of the United States, and, although printed in 1852,[2] it still remains the only monograph devoted entirely to the geology of Texas.

U. S. MILITARY RECONNAISSANCES AND EXPLORATIONS.

Principal military reconnaissances and explorations in Texas conducted by the United States Government.



[1] Texas, p. 388.

[2] Written in 1848–'49 on material collected from 1845 to 1847.

Our Government has always exhibited commendable enterprise in the exploration of its own territory. President Jefferson inaugurated this wise policy during his first administration by sending Lewis and Clarke upon their memorable expedition to the Northwest. Had the State of Texas shared the benefits of the first half of the century that were enjoyed by the States already in the American Union, its geologic and topographic features would now be much better understood. Notwithstanding that Texas was then part of another country, early United States explorations several times traversed its territory, as recorded in the works mentioned below.[1]

In 1806 Major Pike was ordered to ascend the Arkansas River to its source, thence to strike across the country to the head of Red River, and then descend that stream to Natchitoches. By mistake he descended the Rio Grande. He was captured by the Spanish authorities, who sent him home under escort, by way of Chihuahua, El Paso, San Antonio, and the Sabine. His work was of much geographic value concerning the Upper Arkansas region, but added little of value to scientific information concerning Texas. It failed in its original object, to discover the sources of the Red River.

The next year (1807) Lieutenant Freeman and party were sent out by President Jefferson to explore the Red River to its sources, but they were arrested near the eastern border of the present Panhandle of Texas and returned to the United States. The Spanish government, alarmed by these explorations, strengthened its fortifications on the eastern border of Texas to keep out all intruders.

The next Government expedition to penetrate Texan territory was the one conducted by Major Long, in 1819–'20. On his return from the Upper Arkansas he traveled several hundred miles down the Canadian, under the supposition that it was the Red River. A report of his journey was published.[2] This contained an interesting geographic description of the country, with some geologic facts. Although the Canadian region naturally belongs with the Indian Territory, political boundaries have included a portion of it in Texan territory, and hence to Major Long's description of it belongs the credit of being the first practical

[1] Thrall's History of Texas, p. 24.

Exploration of the Red River of Louisiana, by R. B. Marcy, &c., p. 3.

An account of expeditions to the sources of the Mississippi, and through the western parts of Louisiana, to the sources of the Arkansaw, Kans, La Platte, and Pierre Jaun Rivers; performed by order of the Government of the United States during the years 1805, 1806, and 1807. And a tour through the interior parts of New Spain, when conducted through these provinces, by order of the captain-general, in the year 1807. By Maj. Z. M. Pike. Illustrated by maps and charts. Philadelphia, 1810. 8°, pp. 7, 277; 4, 67, 55, 87, 1 portrait, 6 maps.

[2] Account of an expedition from Pittsburgh to the Rocky Mountains, performed in the years 1819 and '20, by order of the Hon. J. C. Calhoun, Secretary of War: under the command of Major Stephen H. Long. From the notes of Major Long, Mr. T. Say, and other gentlemen of the exploring party. Compiled by Edwin James, botanist and geologist for the expedition. 2 vols. Philadelphia, 1823. 8°.

contribution to geologic knowledge of Texas by the Government explorations.

Lieut. J. W. Abert, while returning from New Mexico in 1845, also descended the Canadian River through the northern portion of the Panhandle of Texas. His itinerary and the accompanying illustrations throw some light upon the physical features of the region, but convey little accurate geologic information.[1]

In 1840–'41 a joint commission, representing the United States and the Republic of Texas, ran the Louisiana-Texas boundary. The Journal of the Joint Commission affords no geologic information, although a few facts may be inferred from the meager topographic data. This exploration was exceptional in a period of reconnaissances.[2]

Government explorations were inaugurated in Texas soon after the annexation of that Republic and the subsidence of excitement incident to the war with Mexico which followed.

By the articles of annexation (1845) it was stipulated that the United States Government should protect the people of Texas from the Indians upon their western and northern borders. The settlements at that time did not extend beyond the eastern third of Northern Texas and the city of San Antonio in the south. One of the first acts of the United States Government was to establish a chain of forts from Fort Washita, Arkansas (now Indian Territory), on the Red River, to near the present site of Fort Duncan, near Eagle Pass, on the Rio Grande,[3] including Fort Worth (now the prosperous city of the same name); Fort Graham, on the Brazos, in Hill County; Fort Martin Scott, near the present town of Fredericksburg; Fort Croghan,[4] on the Colorado; and Fort Lincoln, on the Rio Seco, in the southwest corner of Medina County. This chain of fortifications became the base of a series of military explorations in Western Texas that added greatly to the fund of knowledge concerning that region.

The work accomplished was of two kinds, each of which was of some definite value to geologic knowledge. The first was work of reconnaissance for the purpose of obtaining an idea of the general topography of the country in order to facilitate military operations. The second comprised detailed surveys for purposes other than military, embracing the great surveys for the exploration of the railway routes to the Pacific, the exploration of the Red River of Louisiana, the United States and Mexican boundary survey, and an experiment in digging artesian wells on the

[1] Report of an expedition, by Lieut. J. W. Abert, on the Upper Arkansas and through the country of the Comanche Indians, in 1845. Twenty-ninth Congress, first session, Senate Document 438. Washington, 1846.

[2] Twenty-seventh Congress, second session, Senate Document 199, pp. 54–57, with maps.

[3] The northeast and southwest line of this chain of forts almost coincides with the eastern boundary of the true Texas Cretaceous area.

[4] Abandoned.

plains. All these expeditions were conducted by officers of the regular Army, frequently accompanied by scientific specialists.

The greater part of the reports of these expeditions were published, the first in 1850,[1] though some of them can only be found in manuscript in the archives of the War Department at Washington,[2] including all preceding 1849.

The character of the published reports was of every degree of value, varying in length from brief communications of only a page or two to large sets of octavo volumes replete with original matter.[3]

RECONNAISSANCES.

At the close of the Mexican war very little was known of Texas west of the line of fortifications erected in 1846–'47. Not the source of a single river heading in the great plains was definitely known and nothing whatever of the geology of that territory had been revealed.

The first military reconnaissance was that undertaken by Lieut. William F. Smith,[4] February, 1849, for the purpose of reconnoitering a wagon road from San Antonio to El Paso, a distance of 632 miles. His brief report is very general in its character, but gives many hints concerning the topographic features of the country. It contains no direct contribution to geologic knowledge.

The next expedition was conducted by Lieut. N. Michler, jr.,[5] and had for its object the reconnaissance of a military road from Corpus Christi to the military post on the Leona. His report contains numerous descriptions of the topographic features of the region traversed. Although its character is purely that of preliminary reconnaissance and its scientific allusions are vague and incidental, the report still remains one of the best descriptions of that portion of the country.

The next exploration of 1849 was that reported upon by Lieut. William H. C. Whiting.[6] The object of the undertaking can be best understood by the following extract from the original orders under which he acted:[7]

> It being very important that a military reconnaissance should be made of the western frontier of Texas, indicated by the chain of posts now established, commencing at the Rio Seco and terminating on the Red River at the mouth of the False Washita, you have been selected for that duty. You will be pleased to embrace in your report the general character of the country, the roads to be constructed between the posts, timber and stone for quarters, fuel and water, and the healthfulness of the country.

[1] Senate Ex. Doc. No. 64, Thirty-first Congress, first session, 1850. Reports of the Secretary of War. This contains reconnaissances in Texas and adjacent regions by sundry officers in 1849.

[2] For a complete map of Government explorations, see Progress Map of the United States Geographical Surveys West of the One Hundredth Meridian, 1882.

[3] Reports of the United States and Mexican Boundary Survey, 4°, 3 vols.; Pacific Railway Reports, 4°, 12 vols., &c.

[4] Senate Ex. Doc. No. 64, Thirty-first Congress, first session, 1850. Report of the Secretary of War, p. 6.

[5] Ibid., p. 7.

[6] Ibid., pp. 235–250.

[7] Ibid., p. 236.

Lieutenant Whiting's report, made in accordance with the foregoing instructions, is by far the most intelligent and comprehensive of the military reports of that year. While keeping the main object of the journey in view, he does not lose an opportunity to interpolate observations upon the geology of the region. His report, of only thirteen pages, is the best yet made of the country traversed, although its contribution to scientific knowledge is small.

A most important contribution to the topography of the region between El Paso and Fort Washita was made by Capt. Randolph B. Marcy upon his journey eastward from Santa Fé to Fort Smith. His route intercepted the headwaters of the rivers that rise along the eastern borders of the Staked Plains and was subsequently visited by the Pacific Railroad surveys. His report includes the first printed description of the region, which will be treated somewhat at length in subsequent pages.

This journey, the first of a series made by Captain Marcy in that region, furnishes the greater portion of our knowledge concerning it. The publications of his observations consist of a large map, showing the routes traversed by him during the years 1849, 1850, and 1851, and his report upon the exploration of the Red River of Louisiana, the latter belonging to the work of exploration, more fully noted hereafter.

Meanwhile Lieut. W. F. Smith, who had completed his reconnaissance of the country between San Antonio and El Paso, was detailed to explore the Sacramento Mountains west of the Pecos River. His report of the work is only two printed pages, but, comparatively, is a valuable contribution to the topography of the region, about which so little is yet known.

Lieut. Francis N. Bryan conducted another expedition in this year. His object was to survey a road from San Antonio to El Paso. His published itinerary of the forty-six days occupied in performing the journey contains much general information concerning the country traversed.

Another contribution to the geography and topography of Texas was made by Lieutenant Michler in the year 1849. He followed Captain Marcy's trail from Fort Washita to the Pecos River. Upon arriving at the Pecos he turned eastward to San Antonio. His printed report was of a general character.

Other reconnaissances were made during the succeeding years, but little has been published concerning them except what is embodied in the reports of the more detailed explorations.

EXPLORATIONS.

The work of the Government expeditions hitherto made, although often securing valuable data, was purely that of hasty military reconnaissances; but we shall see that the national authorities commenced

a series of more deliberate expeditions, usually accompanied by scientific specialists, beginning with Captain Marcy's exploration of the Red River of Louisiana in the year 1852 and continuing until the completion of the United States and Mexican boundary survey in 1855, and including some minor work extending to the year 1858. Thirty-five years ago little was known of Texas west of the one hundredth meridian; even the headwaters of Red River had not been explored; to-day little is known of this region, and no map exists containing more than an approximation to its topography.

EXPLORATION OF THE RED RIVER OF LOUISIANA.

In 1852 Captain Marcy was ordered to explore Red River to its source. Upon his return he published a report[1] of the expedition, which contains the first geologic contribution of value for that part of the State. From this report is compiled the following résumé of the work accomplished by the exploration and its scientific corps:

(1) Barometric and astronomic observations were made by Lieut. George B. McClellan. Although these were oftentimes incorrect,[2] they constituted a definite contribution to the altitude of that region.

(2) A practical geologist, Dr. G. G. Shumard, accompanied the expedition and made many notes of value, communicating to the world through his own report and the reports of others upon his collections many facts concerning the local geology. His work will be further noticed in this paper.

(3) The source and the confluents of Red River were delineated upon the map.

(4) Collections of botanic and zoölogic specimens of great value were made, upon which many publications were afterwards based.

The strictly geologic work accomplished by this expedition was as follows:

(1) Dr. George G. Shumard, the accompanying geologist, gives a brief description of the country from Fort Smith, Arkansas, westward, by the way of Fort Washita (ten miles north of the present city of Denison, Tex.) and Fort Belknap, Texas, to the headwaters of Red River. His paper contains the first descriptions of the Coal Measures (Carboniferous) of the Indian Territory and Central Texas; many sections of the gypsum bearing region, commonly called the Jura-Trias or Red beds, and the best we now possess of them; descriptions of the Wichita Mountains, composed of granitic rock, which are still but little understood; and interesting data concerning the Cretaceous strata of that region.

[1] Exploration of the Red River of Louisiana, in the year 1852, by Randolph B. Marcy, captain Fifth Infantry, U. S. Army, assisted by George B. McClellan, brevet captain U. S. Engineers; with reports on the natural history of the country and numerous illustrations. Washington, 1854.

[2] Lieutenant McClellan located the one hundredth meridian nearly 70 miles east of its true position, an error which has caused considerable misunderstanding concerning the boundary of Texas.

It is to him that we owe the first presentation of these strata as they occur at Fort Washita and southward from that place in Texas.

(2) A valuable contribution to the mineralogy of the region, by Dr. Edward Hitchcock, of Amherst. His paper treats of the vast gypsum deposits and the economic and scientific value of that mineral as it occurs in Texas.

(3) Descriptions of the Carboniferous and Cretaceous fossils collected, with figures. This, the paleontologic portion of the work, was the first contribution by Dr. Benjamin F. Shumard to the geology of Texas. The figures are very poorly executed and it is doubtful whether their publication has been of value.

(4) A valuable map of the region, by Captain Marcy, accompanies the report. It contains the results of observations during many years of that officer's travels in this region.

UNITED STATES AND MEXICAN BOUNDARY SURVEY.

While Captain Marcy was exploring the northern portion of the State, another expedition was in progress upon a much larger scale along the southern boundary. This was the United States and Mexican boundary survey of 1848–1855. It is well to bear in mind the immense size of the State of Texas and to remember that Marcy's investigations were in the northwestern portion and Roemer's in the southeastern central, the United States and Mexican boundary survey being confined to the southern region.

The work of this survey in Texas commenced in the year 1853, under Major W. H. Emory, and the field work continued through the year 1854. In 1857 the report[1] of the survey was published. This is of inestimable value to science. It contains the first geologic descriptions of the great region drained by the Rio Grande. In fact, the three large quarto volumes of this report, except a few magazine articles, still form almost the sum total of the literature of that section.

The report embraces papers upon the geology of the route by Messrs. Arthur Schott, James Hall, and T. A. Conrad. Messrs. Hall and Conrad had not seen the region, but made vague and general deductions from reports and from specimens collected by members of the party. Mr. Schott's descriptions are clear and accurate so far as I have observed. Mr. Conrad's paleontologic descriptions were too often based upon material that modern paleontologists would not consider trustworthy evidence of new species. In several instances the localities he gives in the publication disagree with the ones marked by the collector, Mr. Schott, upon the specimens now in the collections of the National Museum.

[1] Report on the United States and Mexican boundary survey, made under the direction of the Secretary of the Interior, by William H. Emory, major First Cavalry and United States commissioner. Vol. I. Washington, 1857.

Dr. C. C. Parry, who wrote the paper in Major Emory's report upon the geology of the upper portion of the Rio Grande, states that the portion of the river from seventy miles below El Paso to Presidio del Norte did not come under his personal observation.[1]

These facts are given not to disparage the work, which, as already said, is by far the best contribution to the geology of the Rio Grande from El Paso to its mouth, but to show how infinitesimal is our knowledge of the region of which these small geologic reports are as yet our only authority, a section of country, following the general course of the stream, over twelve hundred miles in length.

The astronomic and topographic determinations of this survey were also very valuable and in general it is the most important and accurate addition to the cartography of Texas that has yet been made.

PACIFIC RAILROAD SURVEYS.

Another Government undertaking that followed closely upon Captain Marcy's exploration of Red River, and that was inaugurated while Major Emory's work upon the Rio Grande was still in progress, was the series of surveys across the region lying between the Mississippi River and the Pacific Ocean, commenced in the year 1853. Two of the lines crossed portions of the State of Texas.

The first of these surveys was conducted by Lieut. A. W. Whipple in 1852 and 1853 and is generally known as the thirty-fifth parallel survey.

The thirty-fifth parallel survey.—This survey traversed that extreme northwestern portion of the State locally designated as the Panhandle (all of Texas north of Red River and west of the one hundredth meridian), a region differing much in its physical aspects from the remainder of the State. The line traveled was approximately that of the Canadian River, and the results were a fair geographic section of the region and a contribution to the scientific knowledge of the Indian Territory, whereby some light was thrown upon the northern extension of the Texas formations.

Lieutenant Whipple, besides having a well equipped corps of topographic engineers, was accompanied by Mr. Jules Marcou, who as geologist took careful notes and collected many specimens. His observations were valuable, but his deductions involved American geologists of the time in a discussion that has not been settled to this day; for, while Mr. Marcou was said to be wrong in certain of his conclusions concerning the so-called Jurassic age of what is now generally accepted Cretaceous, he still possessed the advantage over his antagonists of being the only one who had visited the field. It is often a question in my mind whether Mr. Marcou's terms Jurassic and Neocomian, which he applied to the Cretaceous of Western Texas, are not much nearer the truth than those of the writers who make that portion of the Texas

[1] Report on the United States and Mexican Boundary Survey, Vol. I, Part II, p. 49.

Cretaceous the equivalent of the upper members of the European series. He was one of the first practical geologists to visit this northwestern section of Texas. His observations were limited to that small portion of the State traversed by the Canadian River, but they constitute the chief data concerning the region to which they pertain. It is much to be regretted that their usefulness was impaired by the misunderstanding that ensued between him and the Secretary of War. Before Mr. Marcou could write a final and complete report his notes were peremptorily demanded as he was departing for Europe, and later they were intrusted to Mr. W. P. Blake to write out. He published Mr. Marcou's field notes in full, although he failed in that interpretation which could have been made only by Mr. Marcou, and gave the world an opportunity to make its own deductions.

The results[1] of the thirty-fifth parallel survey, although presenting many imperfections and marred by this unfortunate occurrence, were upon the whole a great addition to our knowledge of the Indian Territory and Northwest Texas regions.

The thirty-second parallel survey.—Another survey across the State of Texas for the purpose of finding a suitable railway route to the Pacific was that conducted by Capt. John Pope along the thirty-second parallel in 1853. Practically the route was the same as the one traveled by Captain Marcy upon his return from New Mexico, in 1848, a description of which has already been given (p. 24). The work of this exploring expedition, so far as it pertained to Texas, commenced at El Paso, in the western portion of the State, and progressed eastward. It approximately followed the thirty-second parallel to near the mouth of Delaware Creek, and thence passed slightly north of eastward to Preston, on Red River, a few miles northwest of the site of the city of Denison. It crossed, en route, the Paleozoic strata of the trans-Pecos region, the Jura-Trias or gypsum bearing series, the typical Texas Cretaceous, the Central Texas Coal Measures, the two belts of the cross timbers, and the Cretaceous to the east of the central Carboniferous exposures. The astronomic, topographic, and barometric measurements were important, but the geologic results were impaired by the fact that no trained geologist accompanied the expedition. The notes of the officers and the specimens gathered under Mr. Marcou's direction, however, were turned over to him by Captain Pope, and he wrote a brief general preliminary report upon them.[2]

[1] Reports of explorations and surveys to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean, made under the direction of the Secretary of War in 1853–'54,–'55, according to the acts of Congress of March 3, 1853, May 31, 1854, and August 5, 1854. Volume III. Washington, 1856.

[2] Report of Secretary of War. House Document 129, Vol. 4, Chap. XIII, pp. 125–128. Geological notes of a survey of the country comprised between Preston, Red River, and El Paso, Rio Grande del Norte, in Report of Exploration of a Route for the Pacific *Railroad near* the Thirty-second Parallel of Latitude, from the Red River to the Rio *Grande. By Bvt. Capt. John Pope,* Corps of Topographical Engineers, 1855.

The notes and specimens of this expedition were taken from Mr. Marcou, together with those of the thirty-fifth parallel survey, and hence he was debarred from the privilege of writing the final report for the large quarto volumes that subsequently appeared.[1] These contained a written report by Mr. W. P. Blake, which gave little additional knowledge.

ARTESIAN WELL EXPERIMENT.

The last exploration in Texas conducted by military officers under specific Government appropriations was that for the purpose of boring artesian wells upon the plains, conducted by Capt. John Pope, in 1857 and 1858.[2] This experiment yielded important geologic information, for accompanying the expedition as geologist was Dr. George G. Shumard, who collected much material and wrote an article on the local geology,[3] adding much to our knowledge of the trans-Pecos region, showing the existence of the Carboniferous, the Cretaceous, and the gypsum bearing Mesozoics in that part of the State.

During this expedition Dr. G. G. Shumard collected the material that formed the ground work of Dr. B. F. Shumard's article upon "New fossils from the Permian strata of New Mexico and Texas." This paper first announced the existence of Permian strata in Texas.[4]

This work practically ended United States explorations in Texas for the time. The State then exhibited a keen desire to explore its own geologic resources. In a few years the civil war drew the energies of our military forces to a more serious field and the posts along the Texas frontier were evacuated, and until the inauguration of work by the United States Geological Survey in the State no further contributions were made by United States explorers.

GEOLOGIC SURVEYS CONDUCTED BY THE STATE.

For the information contained in the following pages I am indebted to various persons. Much of it has been compiled from the official reports

[1] Reports of explorations and surveys to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean. Made under the direction of the Secretary of War, in 1853–'54, according to acts of Congress of March 3, 1853, May 31, 1854, and August 5, 1854. Vol. II. Washington, 1855.

[2] Artesian well experiment. Reports of Capt. John Pope, Top. Eng., to Capt. A. A. Humphreys, Top. Eng., in charge of office of Exploration and Survey, War Department. To be found in Senate Ex. Doc., Thirty-fifth Congress, second session, 1858–'59, Vol. 2 (which is Report of the Secretary of War, J. B. Floyd, first part), pp. 582, 590–608.

[3] Trans. Acad. Sci. St. Louis, Vol. I.

[4] Still little understood, but now considered either Permian or uppermost Carboniferous, being the latest of the latter age.

of the several State geologists. A greater portion, however, has been kindly furnished by those familiar with the facts presented.[1]

The burning of the archives by the capitol fire in 1881 has deprived me of what under ordinary circumstances would be the most useful source of information.

To some it is a matter of surprise that the State of Texas has not made a thorough geologic survey of its territory, especially since the State has always been comparatively free from financial embarrassment and owns the public lands within its borders, the value of which could not but have been enhanced by a scientific knowledge of their characteristics. A thorough study of the political history of the State will show, however, that a combination of untoward circumstances has invariably thwarted the effect of enactments looking toward such a survey.

Up to the time when the Anglo-American population extricated Texas from the Spanish-Mexican régime (1835) it had been under the non-progressive rule of the Middle Ages. The other States of the Union had previously attained a permanent form of government, allowing the public mind to follow intellectual and scientific pursuits with the greatest impetus during the first third of the nineteenth century. Amidst the throes of political organization scientific interests always flag. Time is required for the establishment of a stable government. While undergoing its political evolution, Texas had two wars with Mexico and a continual fight with hostile savages. Twenty years from the date of its separation from Mexican domination seems but a short period for the establishment of a geologic survey.

But a still greater obstacle to an early thorough survey of its domains was the fact that the population, even until the last decade, was confined to the eastern third of the State, and that until a dozen years ago the hostility of the Indians made observation in the vast unsettled region exceedingly dangerous. In 1849 Dr. Roemer said that Texas became interesting geologically at the points where civilization left off and where exploration was almost impossible. His remarks would have been equally applicable thirty years later.

Notwithstanding these obstacles, the State of Texas did establish by legislative enactment and appropriation what was intended to be a thorough topographic and geologic survey of its domains. This honorable design was defeated by the civil war and the petty jealousies of the scientific men to whom the State had intrusted the labor. The State made two earnest endeavors to secure a geologic survey of its domain and that such a survey has not been made is not due to its indifference.

Before describing these surveys and their results, it will be well to mention briefly the Texas land office, an institution whose functions have a distant connection with scientific results.

[1] I am especially indebted to Prof. G. C. Broadhead, of Pleasant Hill, Mo.; Mr. Friench Simpson, of Columbus, Tex.; Hon. A. D. Norton, of Dallas, Tex.; Mr. C. *K. Lee, of Colorado,* Tex.; Hon. J. G. Tracey, of Houston, Tex., and Mr. N. A. Tay*lor, of Abilene, Tex.*

THE TEXAS LAND OFFICE.

The Republic of Texas, having in its possession a large unsettled domain, found it necessary, as one of the first acts of its existence, to establish some method of administering the duties incident to the survey and the disposition of the land. By act of December 22, 1836, a land office was opened at the capital in February, 1838, under the control of a salaried commissioner.

The functions of this office were to preserve a record of surveys, to issue warrants for land, and to prevent error or fraud in their location. The Republic of Texas followed the Spanish method of granting lands,[1] by which the State incurred no expense of survey in their location. Instead of making topographic surveys of the public lands and dividing them according to the township system of the United States land surveys, the State issued scrip for a designated number of acres to be located upon any portion of the territory found vacant. The person locating the land employed a surveyor (oftentimes of inadequate skill), who ran the lines of the location and sent in field notes of his survey to Austin. By this method the State obtained very unsatisfactory information of these surveys. By the township system, on the other hand, at least a correct map of the main topographic features would have been secured. The land office of the State published several maps of Texas, but they were chargeable with incorrectness. Dr. B. F. Shumard said: "The maps in the land office at Austin are more or less imperfect and the surveys in some instances exceedingly erroneous;"[2] yet these maps were the only contributions of the State land office to a scientific knowledge of Texas. Their value is of a doubtful if not of a negative character. The commissioners have made regular reports to each legislative body. A few of these have been printed, but they contain nothing of scientific value. The whole series of reports can be found only in the land office at Austin.

FIRST GEOLOGICAL SURVEY (SHUMARD).

By act of the 10th of February, 1858, the legislature of the State of Texas authorized a geological and agricultural survey of the State. It was made the duty of the State geologist to make as speedily as possible "a thorough and complete geological survey of the State, so as to determine accurately the quality and characteristics of the soil and its adaptation to agricultural purposes; the species of produce to which the soil in different sections is adapted; its mineral resources, their location and the best means for their development; its water powers, their location and capacities; and generally everything relating to the geological and agricultural character of the State."[3]

[1] See p. 12.

[2] First Report of Progress of the Geological and Agricultural Survey of Texas, by B. F. Shumard, State Geologist, pp. 8, 9.

[3] Ibid., p. 5.

To fill the office of State geologist, which was created by the same act, Governor H. R. Runnels, on the 28th day of August, 1858, appointed Dr. Benjamin F. Shumard.[1] This gentleman's life of scientific training and his experience in geologic surveys gave him every qualification for the position.[2]

Organization and equipment.—His first act[3] was to select from the works of the best instrument makers a set of chemical and physical apparatus for the equipment of analytical laboratories at Austin and of meteorologic stations at one or two other points. Since the climatologic and meteorologic conditions existing in the State of Texas are important factors in the geologic effects, the wisdom of Dr. Shumard's endeavors to study these phenomena will be apparent.

He organized his staff of assistants as follows: Assistant geologist, Dr. George G. Shumard; chemist and assistant geologist, Prof. W. P. Riddell; topographer, Mr. A. R. Roessler; meteorologists, Prof. Caleb G. Forshey, at Rutersville, and Swante Palm, esq., at Austin.

The qualifications of all these gentlemen were considered the best for their day and time. Dr. George G. Shumard possessed the largest store of scientific information, especially concerning the western portion of the State, having accompanied Captains Marcy and Pope as a geologist in their numerous explorations.

Professor Riddell, besides being an able chemist, was especially well informed respecting the structure of the settled portion of the country.

Mr. Roessler, although a young man, possessed a good scientific education, was a hard worker, and to him is due much of the accurate topographic knowledge of the State we possess at the present day.

The meteorologic stations were established in accordance with the plan adopted by the Smithsonian Institution.

Field labors.—The geologic corps proper was divided into field parties, and in January, 1859, these entered upon their duties. The first of them, under Dr. George G. Shumard, constructed an accurate section of the country between Austin and the Red River in Grayson County. Dr. Shumard also made "thorough and final surveys" of the counties of Grayson, Fannin, and Cass, and partial surveys of Bowie, Red River, and Lamar Counties. In addition to this work, he made a

[1] There is a tradition, with some ground for belief, that Governor Runnels intended to appoint Dr. G. G. Shumard to the office of State geologist, but, by a clerical error, the name of his brother, Dr. B. F. Shumard, was inserted in the original commission. This being before the days of rapid communication it was impossible to remedy the error, and Dr. G. G. Shumard gracefully accepted the position of assistant State geologist.

[2] For a sketch of Dr. Shumard's qualifications, see Texas Almanac for 1859.

[3] The following account of the operations of the survey is principally based upon the First Report of Progress of the Geological and Agricultural Survey of Texas, by B. F. Shumard, Austin, 1859.

careful exploration of Red River from Cooke County to the Louisiana boundary.[1]

Professor Riddell made final surveys of the counties of Caldwell and Guadalupe, south of Austin, the State capital, and of McLennan and Coryell, near the geographic center of the State; also of the greater part of Bosque County.

Dr. Benjamin F. Shumard, the head of the survey, made detailed surveys of Burnet and Rush and partial surveys of Travis, Bastrop, Washington, Fayette, and Young Counties. He also made a series of reconnaissances. Dr. Shumard in his report[2] said:

It will be seen that besides a general survey extending over a large portion of the eastern and middle portions of the State, we have made minute and final surveys of eleven counties. Two are nearly finished and a number partially surveyed.

Methods of survey.—From the report cited we extract the following:

In making these preliminary surveys careful sections of the strata have been made at all points of outcrop within reasonable distances of the route traveled, and the thickness, stratigraphical order, dip, and mineral and fossil characters of the various beds have been determined with as much precision as possible. * * * In some counties sections of the strata have been measured at more than one hundred and fifty localities. * * * We made frequent barometrical observations to ascertain the elevation of the country above tide-water, and much attention has been directed to obtaining a correct knowledge of the topographical features.

We have also determined, with as much accuracy as possible, the amount and quality of timber in each county, proportion of timber and prairie, elevation of hills, depth and width of valleys, and the amount of available water power furnished by the streams.

A large share of attention has also been devoted to the agricultural capabilities of these counties. The different varieties of soils and subsoils have been carefully examined, numerous specimens have been collected for future study and analysis, and we have spared no pains to ascertain the most advantageous methods of cultivating and improving them.

Particular search has been made for minerals of economical importance, and all mines, whether of prospective or known value, have been examined with special care and the probable amount, richness, and quality of the ores determined. Samples of ores and their accompanying minerals, coals, limestones, marbles, clays, mineral waters, &c., have been collected, and are now deposited in the laboratory at Austin, for chemical analysis and final preservation in the State cabinet.[3]

[1] Since this work was prepared for the press the notes of Dr. G. G. Shumard have been collected and published by the State of Texas in a volume entitled "A Partial Report of the Geology of Western Texas, consisting of a General Geological Report and a Journal of Geological Observations along the Routes traveled by the Expedition between Indianola, Tex., and the Valley of the Mimbres, New Mexico, during the years 1855 and 1856; with an Appendix giving a detailed Report of the Geology of Grayson County. By Prof. George G. Shumard, assistant State geologist of Texas. Austin, State Printing Office, 1886." 8°, pp. vii, 145, with illustrations.

[2] First Report of Progress of the Geological and Agricultural Survey of Texas, by B. F. Shumard, State geologist, p. 8.

[3] Ibid., p. 8.

Of the fossils, Dr. Shumard remarked that the collection was "especially large and valuable, and, it is believed, when carefully studied will throw considerable light on some disputed points of the geology of the West and Southwest."

Maps.—On the subject of maps Dr. Shumard said:

Our county maps will embrace the areas occupied by the different geological formations, localities of workable mines, ore deposits, coals, lignites, marble and stone quarries, medicinal and other springs, furnaces, towns, post offices, churches, saw and grist mills, and boundaries of timber and prairie. This portion of our labor has often been attended with considerable difficulty, arising from the fact that the maps in the land office at Austin are more or less imperfect and the surveys in some instances exceedingly erroneous. It has been sometimes almost impossible to locate our observations with that degree of minuteness and precision which was thought desirable, but we have spared no exertions to remedy defects, supply omissions, and to make our maps as complete as possible in their geographical as well as in their geological details.

Such is a brief account of the first year's operation of the geological and agricultural survey of Texas, as stated by its director in his first annual report of progress. It is obvious that Dr. Shumard had accomplished much during this brief time and that the plans of organization and operation were such as to result in the accomplishment of one of the most valuable State surveys, could they have been carried out.

Operations of 1860.—After a brief winter's work in quarters at Austin, the Survey resumed the field in 1860. The records of the year's work are meager, for a series of misfortunes occurred by which the results of the survey, excepting a few fragments to be hereafter noted, were lost to science, and a blow was inflicted upon State encouragement of scientific investigations from which the State has not yet recovered.

The personnel of the scientific corps remained unchanged, except that at the beginning of the year Dr. Shumard employed as a collector of plants a young man, S. B. Buckley, who became a prominent figure in the subsequent history of the surveys.

From Mr. Buckley we have the only published account of the survey's operations during the year,[1] of which he speaks as follows:

In January, 1860, I was also employed as an assistant by Dr. Shumard, I having charge of the botanical department, also making geological observations.

In May, 1860, Drs. Shumard, Riddell, and myself went, via San Antonio, to Corpus Christi, returning by the way of Goliad and Lockhart to Austin. About the 1st of June we started for the survey of Navarro County, which was finished about the 1st of July; then we removed, spending the month of July in the survey of Washington County. The month of August was employed in the examination of Bastrop County. Thence returning to Austin, we went into San Saba, remaining there until November.

Dr. George G. Shumard spent the summer in Northern Texas, in Grayson, Lamar, Fannin, and other counties on the Red River. He returned to Austin in September.

During the summer Dr. B. F. Shumard had been a large portion of the time at Austin, leaving Dr. Riddell and myself in the field. At Austin he was closely watched by Governor Houston, who, being convinced that Dr. Shumard was not a suitable person for a State geologist, removed him about the 1st of November, 1860.

[1] First Annual Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, A. M., Ph. D., State geologist, Houston, 1874, p. 8.

On the same page from which the above is quoted and on the following one Dr. Buckley shows very plainly the spirit in which he served his chief. He says:

Returning in January, we found Dr. Shumard still at Austin, occupying his former room at the geological department. Dr. Moore thought it rather strange that Shumard had not vacated the office. In excuse, Dr. Shumard assured Dr. Moore that he would do nothing which would injure the interests of Dr. Moore, and that he only wished to arrange his business and start for the North. Thus assured, we started for Llano County, but on our route Dr. Moore, thinking that all might not go right at Austin, where the [secession] convention of 1861 was then in session, requested me to return and arrange specimens, and watch Dr. Shumard, with whom I was then on friendly terms. Soon after my arrival at Austin a friend informed me that Dr. Shumard was busily engaged in persuading the members of the convention to displace Dr. Moore and reinstate him in office again, and that, too, with every prospect of success. To thwart this, I drew up some charges against Dr. Shumard and placed them in the hands of Governor Houston, who showed them to some of the leading members of the convention, and nothing further was done in favor of Dr. Shumard, who soon after left for St. Louis, vowing vengeance, saying that he would break down my scientific reputation.

Mr. Roessler says:

Aside, however, from Mr. Buckley's own acknowledgment of his motive in drawing up these charges, he shows his maliciousness and willful intention, if possible, to suppress the truth by neglecting to state that when these charges were presented the legislature of Texas, in its session of 1860–'61, appointed a committee for their investigation, of which Mr. Waelder was chairman. He also neglects to state that Dr. Shumard courted an investigation and voluntarily and promptly appeared before the committee appointed, and that the utter falseness of the charges was proved by such well known gentlemen as Professor Forshey, Senator Russell, and Colonel Timmons.[1]

A State election had occurred in the fall of 1859, and after much bitterness on both sides Governor Runnells, the democratic incumbent and the patron of the survey, was succeeded by Gen. Sam. Houston, independent, who, under the influence of political and personal effort brought to bear for that end, removed Dr. Shumard, after an administration of twenty-six months.[2] Dr. Shumard left the State at the outbreak of the war, during which most of his notes, collections, and maps were lost or destroyed, and made his home at St. Louis, where he died in 1869,[3] having had no opportunity to publish an official report, but having contributed to our knowledge of the geology of Texas by his fragmentary pub-

[1] Reply to the charges made by S. B. Buckley, State geologist of Texas, in his official report of 1874, against Dr. B. F. Shumard and A. R. Roessler, p. 7.

[2] Dr. Shumard was reinstated by the legislature, in April, 1861, to prepare his final report, which was never published.

[3] For the biographical data concerning Dr. Shumard in this paper we are indebted to the sketch in the Am. Jour. Sci., 2d ser., Vol. XLVIII, pp. 294–296; to A. R. Roessler's reply to S. B. Buckley; and to Prof. G. C. Broadhead and others.

Dr. B. F. Shumard was born at Lancaster, Pa., November 24, 1820. His father afterwards removed to Cincinnati, and while he was living there Dr. Shumard graduated at Oxford, Ohio; returning to Philadelphia, he went through one course in the medical college of that city. His father then removed to Louisville, Ky., where young Shumard completed his medical studies, in 1846. He then practiced medicine in one of the interior towns of Kentucky. Here he developed his taste for paleontologic investigation, and after a few months' country practice he removed to Louisville. In this

lications, of which we shall speak more definitely hereafter. The survey as carried on under his immediate successors may, for convenience, still be called the Shumard survey, as it was an attempt to continue his work rather than to inaugurate any new system of work or of organization.

Immediately upon the removal of Dr. Shumard, November, 1860, the governor appointed Dr. Francis M. Moore State geologist. He was an honorable and cultured gentleman, of much executive ability. For many years he had been the editor of The Houston Daily Telegram, then the leading newspaper of the State. It was owing to his public spirited and intelligent advocacy of its necessity that the survey was originally established.

According to Dr. Buckley[1] he himself was appointed first assistant State geologist; Dr. Riddell, who had been assistant State geologist and chemist, was retained as chemist; and Mr. Roessler was

city he became associated in scientific and professional pursuits with Dr. L. P. Yandell, and together they devoted much of their leisure to the study of geology and paleontology. Several valuable paleontologic contributions were published under their joint authorship. Dr. Shumard was an earnest and careful collector, and his cabinet at Louisville was visited by many distinguished foreigners.

Dr. Shumard's geologic talent was not long in receiving recognition. He was appointed by Dr. David Dale Owen as assistant geologist in the geological survey of Iowa, Wisconsin, and Minnesota, which was inaugurated in 1846 by authority of Congress.

Dr. Shumard was busily engaged in the field during 1848 and 1849 as the head of one of the divisions of the survey. Many of the most valuable reports upon the geology and paleontology of this survey, from his pen, "remain monuments to the industry, acquirements, and ability of their author."

Besides his share in the publication of these reports, Dr. Shumard, about the same time, published a valuable monograph, entitled Contributions to the Geology of Kentucky. In the work of the Iowa, Wisconsin, and Minnesota survey he was associated with many men who have since become eminent in the annals of North American geology, including F. B. Meek, Dr. J. Evans, Prof. A. Litton, and others.

In 1853 Dr. Shumard removed to St. Louis and was appointed assistant geologist and paleontologist of the Missouri geological survey under Professor Swallow. He labored here until the summer of 1858, when he was appointed State geologist of Texas. He arrived at Austin on October 30 of the same year and initiated the work of a survey upon a broad and comprehensive plan.

At the beginning of the war the doctor returned to St. Louis. He was obliged to leave a large part of his collections and library at Austin through the war. He again took up the practice of medicine, which he continued to the year of his death.

He had been in a declining state of health for about a year, having suffered from hemorrhage of the lungs, when his death occurred, April 14, 1869.

In St. Louis Dr. Shumard had the intellectual and social companionship of that small coterie of western scientists who made that place a scientific center for many years.

As a paleontologist he held a high rank. He was president and one of the organizers of the Academy of Science of St. Louis and a member of many other similar societies at home and abroad.

He was a man of science in the highest sense of the word and devoted himself entirely to its pursuits; in the prosecution of it he contributed more, perhaps, than any other man to the revelation of the immense resources of the Mississippi Valley.

[1] *First Annual Report of* the Geological and Agricultural Survey of Texas, p. 8.

retained as draftsman. In December, 1860, Drs. Moore and Buckley[1] made a short reconnaissance through the southern counties of the State, and in March they made a tour through Western Texas, during which trip the survey was suspended. The resolution suspending the survey is as follows:

Be it resolved: (1) That the geological survey be suspended, with the exception of the State geologist and chemist, who shall continue in the survey only so long as it may be necessary to make out the report hereinafter provided for.

(2) That B. F. Shumard, the State geologist, be requested to make a report of his survey so far as the survey has been completed, and for that purpose shall have control over the cabinet and rooms and his notes and the services of the chemist, and he shall receive a like salary heretofore paid the State geologist until the work be completed: *Provided,* Said report shall be made by the 1st of July next; which compensation shall be paid out of the appropriations heretofore made for the support of the geological bureau.

(3) That Dr. Francis Moore, present State geologist, be requested to make out a report of the work executed up to the present time.

Approved, April 8, 1861.

What was done towards complying with this act cannot be ascertained. It is certain that no reports were published and apparently the agitation of the civil war prevented further work. The act seems to imply an official justification of Dr. Shumard, which is not mentioned in any of Dr. Buckley's sketches of the history of the surveys.

The civil war had now broken out and Dr. Moore left for the North in July, 1861, and in 1864 died in Northern Michigan, while in the employ of a mining company.

During the war the State capitol was occupied by troops and the laboratories and the museum of the survey were converted into a manufactory of percussion caps. The magnificent specimens were taken away as curiosities or wantonly destroyed and many of the precious notes and maps were scattered to the winds.

At the opening of the war Dr. Buckley also left the South, taking with him, as has been charged by Mr. Roessler,[2] the notes of the survey. At the close of the conflict he returned to Austin, assumed charge of the collections and effects of the survey, and secured the passage of a joint resolution repealing the act of April 8, 1861, by which the survey had been suspended. He was appointed by Governor Throckmorton, in November, 1866, to take charge of the survey, notwithstanding the protests of Dr. B. F. Shumard,[3] Mr. Roessler, and others, previously of

[1] First Annual Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, p. 8.

[2] Reply to the charges made by S. B. Buckley, State geologist of Texas, in his official report of 1874, against B. F. Shumard and A. R. Roessler, p. 10.

[3] In a letter to Swante Palm, esq., under date of August 11, 1866, Dr. Shumard thus characterizes Mr. Buckley's standing in his service: "In the same article he claims that he was connected with me in the geological survey. Now, he came to me ragged and penniless, and I employed him to collect plants at one dollar per day, giving him precisely the same wages I was giving my teamsters and cooks. All the geology he knows I taught him, and that was precious little."

the survey. The unfinished report of Dr. Shumard, which the legislature in 1861 had given to Dr. Moore to complete, now fell to his charge so far as materials remained. Dr. Buckley put forth in 1866 a work entitled A Preliminary Report of the Geological and Agricultural Survey of Texas. In a prefatory note he speaks of the book as the report of work done under the supervision of Dr. Moore, adding that his connection with the survey had been longer than Dr. Moore's and that all the knowledge obtained by service under Dr. Shumard which promises to have any public value is embodied in its pages. The book contains 92 octavo pages, including title and index, and a large proportion of these pages is occupied with general statements as to agricultural operations and the whole is of little scientific value. In the words of Mr. A. R. Roessler:[1]

> It does not contain the analysis of either soils or minerals or the delineation of a single fossil, geological section, or anything else in that direction. In fact there is nothing new in it, the whole report being a poor rehash of articles published in the Texas Almanac and other periodicals.

In 1867 the political winds blew out the administration that upheld Dr. Buckley before he printed any further report. Under military rule and changes that ensued was swept away the last remnant of the original geological survey of Texas as inaugurated by Dr. Shumard nine years before, except a few disordered specimens, which were completely destroyed by the capitol fire in 1881.

Official results.—The destruction of records by the capitol fire leaves no opportunity to gather official information as to what was accomplished by the survey, but from unofficial sources I have endeavored to make up as accurate and complete a statement as possible.

There were two direct publications of the survey. The first was the First Report of Progress of the Geological and Agricultural Survey of Texas, by B. F. Shumard, State geologist. It was a pamphlet of 17 pages, of which 1,700 copies were printed for distribution. It may be found in the libraries of the National Museum and the U. S. Geological Survey at Washington. The second official publication was A Preliminary Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, 1866, already described.

Indirect results.—Although the State published so little concerning the geological investigations of the Shumard survey, the scientific men who were attached to it made known useful data concerning the geology, topography, and paleontology of the State. Dr. Shumard described many new species and contributed much to the stratigraphic knowledge of the State. His publications, based upon material gathered and observations made while connected with the State survey, are as follows:

[1] Reply to the charges made by S. B. Buckley, p. 11.

"Observations upon the Cretaceous strata of Texas," Acad. Sci. Saint Louis, Vol. I, pp. 582–590, 1860.

"Descriptions of new Cretaceous fossils from Texas," Trans. Acad. Sci. Saint Louis, Vol. I, pp. 590–610, with figures, 1860, published by Dr. C. A. White in his Contributions to Paleontology, No. 1, Eleventh Annual Rep. U. S. Geological (Hayden) Survey.

"Descriptions of five new species of Gasteropoda from the Coal Measures, and a Brachiopod from the Potsdam Sandstone of Texas," Trans. Acad. Sci. Saint Louis, Vol. I, pp. 624–627, 1851.

"State House artesian well at Austin," Texas Almanac, pp. 161, 162, 1860; gives valuable geological section.

"Geological survey of Texas," Texas Almanac, pp. 199, 200, 1860, Galveston, 1859.

"The Primordial zone of Texas, with descriptions of new fossils," Am. Jour. Sci., 2d ser., Vol. XXXII, pp. 213–321, 1861.

"Descriptions of new Cretaceous fossils from Texas," Proc. Boston Soc. Nat. Hist., Vol. VIII, pp. 188–205, 1861–1862.

"Observations on the Cretaceous strata of Texas," Texas Almanac, pp. 203–205, 1861.

Extract from a letter to the corresponding secretary of the Academy of Science of Saint Louis, read November 5, 1860; mentions the discovery of dicotyledonous leaves in the Cretaceous strata of Red River, Trans. Acad. Sci. Saint Louis, Vol. II, pp. 140, 141.

"Descriptions of new Paleozoic fossils," Trans. Acad. Sci. Saint Louis, Vol. II, pp. 108–113, 1862; describes *Goniatites Texanus*, a new Carboniferous fossil from the bluffs of Wallace Creek, San Saba County, Texas.

Communication to the Academy of Science of Saint Louis, March, 1861, announcing the apparent discovery of the Ripley group of the Cretaceous in Texas, Trans. Acad. Sci. Saint Louis, Vol. II, p. 152.

At the time of his death Dr. Shumard had in his possession many valuable notes and unpublished manuscripts concerning the geology and paleontology of Texas that would, no doubt, throw much light upon some of the important points concerning that region. Dr. C. A. White has published illustrations of some of the species[1] he described without figures, and this will probably be done in the case of others of his unfigured specimens as soon as duplicates can be collected and identified. The notes and manuscripts, however, should not be lost to science, and it is hoped that some friend of the deceased will produce them ultimately for publication.

Mr. Roessler, the topographer of the survey, has published several valuable maps, among them a large topographic map of the State, printed in 1874, embodying the plans set forth by Dr. Shumard in his report of progress.

The final remnant of the collections remained for many years in the capitol building at Austin, until the burning of that structure in 1881 completely destroyed the last trace of them.

Expense.—It is impossible to ascertain the exact cost of the Shumard survey to the State of Texas from the date of its inception, November, 1848, until the publication of Dr. Buckley's report in 1866. Dr. Buckley states that Dr. Shumard expended $28,000 during the twenty-six months of his administration, which was $8,000 in excess of the appropriation.

[1] Contributions to Invertebrate Paleontology No. 2. Twelfth Annual Report U. S. Geological and Geographical Survey of the Territories. F. V. Hayden, U. S. Geologist. Part I, Geology, Paleontology, and Zoölogy. See pp. 22, 38, 39.

The following items of expenditure are mainly compiled from Dr. Shumard's First Report of Progress, pp. 16, 17. They represent the disbursements of the first fourteen months of his administration:

Salaries: Chief geologist, at $3,000; two assistant geologists, at $1,500 each; topographer, at $600; various subordinates: aggregating	$7,195 71
Equipment (including fitting up of office, apparatus, laboratories, stables, purchase of teams, camp equipment, &c.)	4,947 62
Traveling and transportation expenses	2,845 96
Office expenses	83 71
Total expenditure	15,073 00
Deduct cost of equipment	4,947 62
Actual running expense for fourteen months	10,125 38

The expense of the continuation of the survey under the four months of Dr. Moore's administration cannot be obtained. Based upon the cost of Dr. Shumard's for a similar time they could not have exceeded $4,000, for it must be remembered that retrenchment was the watchword under which he was appointed to the directorship.

The cost of Dr. Buckley's administration for one year could not have exceeded $4,000, as he had no assistants and the State was only at the expense of his salary and the cost of publishing his pamphlet. It may be fairly estimated that the total expense of this survey to the State was less than $25,000.

THE SECOND GEOLOGICAL SURVEY (GLENN-BUCKLEY).

Since the disastrous end of the Shumard survey in 1867 little work of positive scientific value has been done by the State of Texas. When the immediate effects of the civil war had passed away and the political excitement of the reconstruction period had subsided, the expediency of reorganizing the State survey was again broached.

To distinguish it from the Shumard survey, described in the previous pages, this new organization may be called the second geological survey or the Glenn-Buckley survey. It accomplished even less than the first one.

By legislative enactment, approved August 13, 1870, the governor was authorized to appoint a State geologist, with the consent of the senate, the incumbent to give security in the sum of $5,000. The State geologist was to appoint two assistants, one of whom was to be an expert chemist and mineralogist. The duties of the survey were to make a descriptive survey of the State, and an agricultural, geologic, and mineralogic examination and classification of rocks, soils, minerals, mineral waters, fossils, &c. Rooms were to be provided by the governor for the deposit and arrangement of specimens by the geologist. A report of progress was to be made to the governor at each regular session of the legislature. The salary of the principal geologist was to be $3,000; of the *principal assistants*, each, $1,800, traveling and incidental expenses to

be paid by the State. Appointees were required to take an oath of office, agreeing not to purchase, with the view of speculation, any landed or mining interest in the State during their term of office and not to conceal any information relative to any discovery &c. The governor was authorized to offer for sale the reports, when published, to citizens of the State, at a cost not to exceed that of publication, proceeds to be placed to the credit of the common school fund. The State geologist was allowed fifty copies for distribution to scientific men and the assistants twenty copies each. The governor was empowered to remove for neglect or malfeasance in office. All former laws were repealed.

Early in 1873 Governor Edmund J. Davis appointed John W. Glenn State geologist. In November he took the field, with Charles E. Hall as first assistant, and went into Burnet, Llano, and San Saba Counties,[1] returning to Austin in January, 1874, and soon afterwards he resigned. In view of the destruction of the archives it is satisfactory to have Mr. Glenn's direct statement regarding his connection with the survey, kindly furnished in reply to a request for it, and not without value in its bearing upon the work of others in the same field.

LETTER OF MR. J. W. GLENN.

NEW ORLEANS, LA., *August* 7, 1886.

DEAR SIR: Reply to your letter has been delayed until now from necessity of referring to the comptroller of Texas for some details of expenditures which I had forgotten.

I reply to your interrogatories in their order, viz:

1. I was State geologist for Texas from March 31, 1873, to March 6, 1874, when I resigned.

2. The expenses of my administration for that time were $3,637.34.

3. I had no predecessor; my successor was S. B. Buckley.

4. Mr. Rossiter was never State geologist. One A. B. (or A. R.) Roessler was a draftsman in the geological department in 1861 under Dr. Shumard. He was also employed in printing and distributing circulars &c. in 1875 and 10,000 copies of Texas maps in 1875.

A geological survey of Texas was authorized by law and prosecuted to some extent under Dr. Shumard, but was brought to an abrupt ending in 1861 by the war. Nothing further was done until 1873, when I was appointed under a law just then passed, which law contemplated a complete work.

The disorders of the time and want of proper appreciation of the importance of geological work on the part of the public caused me to resign, and S. B. Buckley, who in 1861 was an employé of Dr. Shumard in the division of botany, was appointed my successor. His official existence was brief and barren of scientific results. I have always regarded Roemer's report on the Cretaceous in Texas with favor, and have found that Dr. Shumard's reports, so far as they were published, agree in the main with my examinations; and Roemer and Shumard may be considered as the sole authorities on the geology of Texas up to 1873, unless we add to them part of the United States boundary report.

No publication was made of any of my reports. Before I assumed the duties of State geologist I was familiar with the area and outlines of the coast formations,

[1] First Annual Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, p. 13.

Tertiary, Cretaceous, and the Carboniferous, in the northern part of Texas. My first work was to establish a base line which would include outcroppings of the known formations. As established, this line began in Blanco County, in the Cretaceous, thence northward until it encountered the Cretaceous again overlying the Carboniferous in the north part of the State.

Between these two ends of the base line, beginn ing at the south end, it passed through the following formations in the order as stated, viz: Cretaceous, Carboniferous, Upper Silurian, Lower Silurian, Azoic, Lower Silurian, Upper Silurian, Carboniferous, Cretaceous.

The result was one of the most interesting I ever accomplished. Every square mile of the territory surveyed was carefully platted on the map and defined in the field, and each one numbered and worked over with great care, and the collections taken from each bore its number and from what part each came. Probably the most valuable part of my work, from an economic stand, if the report of it had only been promulgated in print, was my report on the wild sumach of Texas (*R. copallina*), from detailed analyses extending through the entire growth and determining the period of greatest economic value in tannic acid.

These analyses were made by Mr. George H. Katteyer, in the most elaborate and painstaking way, and included an amount of exact information which, owing to the vast growth of wild sumach in Texas, would have proved of immense value to her people in that new industry.

The paleontology of Texas is to me more interesting than that of any other part of the country, especially in the Carboniferous and Lower Silurian formations.

I believe I have replied substantially to all of your inquiries. If not, and you will indicate where, I will gladly supply the omission.

Respectfully, JOHN W. GLENN.

ROBERT T. HILL,

Assistant Paleontologist, U. S. G. S., Washington, D. C.

OPERATIONS OF 1874.

In March, 1874, Governor Richard Coke appointed Dr. S. B. Buckley State geologist. Dr. Buckley appointed Prof. Richard Burleson assistant geologist, Charles E. Hall subassistant, James E. Horn book-keeper and commissary, having Friench Simpson and Jack Coke as volunteer assistants without wages. Field work was begun May 11, and William D. Carrington, Ed. Shands, and a cook were of the party. Dr. Buckley says of his summer's work:

Our trip during the summer has only been a general reconnaissance or partial survey of the following counties. [Here follow the names of forty-five counties.]

No detailed surveys have been made, the object being merely to ascertain the leading geological, mineralogical, and agricultural features of the counties visited as a guide to future examinations and aid to the capitalist and immigrant.[1]

Although during a part of the time Professor Burleson traveled with a subparty over a separate route, it is clear that in covering such a scope of country the field work consisted of little more than a jaunt in an ambulance, rarely deviating from the main road.[2]

The parties traveled rapidly from day to day, gathering fossil and mineral curiosities and noting extravagant stories of agricultural possi-

[1] First Annual Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, p. 16.

[2] See The Coming Empire, or Two Thousand Miles in Texas on Horseback, by H. F. *McDaniels and N. A. Taylor*, New York, A. S. Barnes & Co., 1878, p. 315.

bilities by farmers along their routes. No stratigraphic or topographic work was done, nor were any barometric or other measurements made. From the first annual report of the survey, already cited, some localities can be identified, but its 142 octavo pages are essentially devoid of scientific interest. No office or laboratory work was reported.

The expenses of the half year from May 1 to November 1 are given as follows:

Camp outfit	$1,508 50
Field expenses	871 15
Help	750 00
Total[1]	3,129 65

From Mr. Friench Simpson, of Columbus, Tex., one of the gentlemen who accompanied Dr. Buckley as a volunteer assistant, I have received the following detailed account of the appropriations and expenditures of the survey for the first year of its existence:

Total amount of appropriation		$7,250 00
Salary of geologist	$3,000 00	
Office and chemical supplies	300 00	
Wood	50 00	
Books and instruments	200 00	
Traveling expenses	2,700 00	
Total expenditures	6,250 00	
		6,250 00
Returned to treasury		1,000 00

OPERATIONS OF 1875.

The work of 1875[2] was in continuance of the plan adopted the preceding year of ascertaining, by a general reconnaissance of the State, its main geologic and agricultural features.

The observations for this year were mostly made in the region west of the Colorado River and north of latitude 29°. These observations were of the same general character as those of the preceding year, except that a barometer was introduced into the survey and a few altitudes were recorded.

For an account of the expenses of this year we are again indebted to Mr. Simpson. They were as follows:

Salary of the geologist	$3,000 00
Office and chemicals	500 00
Traveling expenses	2,000 00
Postage	200 00
Fuel	50 00
Total expenses	5,750 00

[1] First Annual Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, p. 119.

[2] Second Annual Report of the Geological and Agricultural Survey of Texas, by S. B. Buckley, A. M., Ph. D., State geologist, Houston, 1876, p. 5.

At the end of the fiscal year Governor Richard Coke, who had himself appointed Dr. Buckley, being convinced that the geological survey as conducted was of no value to the State, vetoed the annual appropriation, thus terminating the survey. The two reports cited contain all the contributions made, to my knowledge, by the reorganized survey, and the State has done no work of the kind since.

RECENT MISCELLANEOUS INVESTIGATIONS.

Some additions to the geologic knowledge of Texas have been made by individual contributors.

Most of the papers contributed were only semi-scientific, written with a view to furnishing popular descriptions of the region. Many of them are now lost, owing to the destruction of the obscure mediums in which they were published.

INDIVIDUAL CONTRIBUTORS.

Previous to the civil war several gentlemen, residents of the State, contributed articles to the southern press upon these questions.

Professor Caleb G. Forshey and *George Wilkins Kendall* were among them. To secure a complete list of their writings would now be impossible, but many of them are still extant in the almost inaccessible files of New Orleans and Texas papers and in De Bow's Commercial Review.

Since the civil war not many residents of the State have contributed to its geologic literature. There have been one or two gentlemen, however, who have been interested in the geology of their State.

N. A. Taylor has contributed many articles to the press of the State, as well as written a book that contains valuable data concerning the geologic features of Texas. While his works are lacking in the exactness of detail that is necessary in scientific matter, his deductions are original and oftentimes so plausible as to seem worthy of extended development and treatment. Unfortunately most of Mr. Taylor's contributions are now inaccessible, he himself being unable to furnish a complete list of them or of their dates and places of publication. His little book[1] contains much general information of value to one who contemplates studying this region.

Ex-Governor Oran M. Roberts[2] gives much information concerning the physical geography of the State. Perhaps no other man is so thoroughly acquainted with the general topography of Texas as he. His observations are acute, but he makes no claim to modern scientific knowledge and the valuable data he gives are unaccompanied by geologic deductions.

[1] The Coming Empire, or Two Thousand Miles in Texas on Horseback, by H. F. McDaniels and N. A. Taylor. A. S. Barnes & Co., New York, 1878. 12°, 390 pp.

[2] A Description of Future Texas; Its Advantages and Resources, with Some Account of their Development, Past, Present, and Future, by O. M. Roberts, Present Governor of Texas, St. Louis, Mo., Gilbert Book Company, 1881.

W. F. Cummins has also written many valuable papers for the State press. His observations are wide, but his writings are valuable for the localities they give rather than as direct contributions to stratigraphy. Mr. Cummins has been of great service as a collector, having made Prof. E. D. Cope's vertebrate collections in Texas. A list of his sketches in periodicals is given below.[1] He has an important mass of unpublished material.

Dr. Charles A. Ashburner made an economic study of the coal fields of Northwestern Texas in 1881 on behalf of certain railroad companies. He contributed a valuable paper to the American Institute of Mining Engineers upon the geology of the region.[2]

Professor E. D. Cope has spent much time in Texas studying its zoölogy. He also studied the fossil vertebrata collected for him. Unfortunately for science, this gentleman made the stratigraphic and geographic information of secondary value, and, in addition to giving few localities, has accepted as present in Texas a geologic formation the existence of which has not been scientifically demonstrated. His brief exposition of the areal distribution of the formations[3] is one of the most valuable extant upon that subject, but it contains an interpretation from which I dissent. He says:

> To the eastward of this line [the eastern border of the Cretaceous] a belt of the Laramie extends from the northeast and terminates at the south, without continuing immediately to the west.

It does not seem to me that this is the Laramie in any sense of the word, for, although it may have been synchronously deposited it has no paleontologic or lithologic resemblance to what the great authorities on that formation have described and located as the brackish water Laramie of the West. This view is based upon my personal observation of both the true Laramie of the West and what Professor Cope terms the Laramie in Texas. It is true that both formations belong to the uppermost Cretaceous or the lowest Eocene, but I think that conclusive stratigraphic and paleontologic evidence exists to show that Professor Cope's Texas Laramie is but the southern continuation of the lignitic formation of Mississippi and Arkansas or the Eolignitic group of Heilprin.

Professor Cope has also described numerous vertebrate remains from what he terms "the Permian formation of Texas." These beds should not be confounded with the trans-Pecos Permian beds of the Messrs.

[1] "Texas geology," Galveston (Texas), Daily News, December 1, 1884. "Geology of North Texas," "Permian formation in Texas," "Tertiary coals in Texas," "Carboniferous formation in Texas," and "Artesian water on the Staked Plains;" these articles were published in the Dallas (Texas) Herald and the Galveston (Texas) News at various times. The exact dates Mr. Cummins cannot give.

[2] "Brazos coal-field, Texas," Trans. Am. Inst. Min. Eng., Vol. IX, pp. 495–506, 1880–'81.

[3] On the Zoölogical Position of Texas, by Edward D. Cope, Bulletin No. 17, U. S. Nat. Mus., pp. 5–8.

Shumard, which are now known to be late Carboniferous. Professor Cope's use of the word is not verified by stratigraphic or invertebrate paleontologic data so far published.

Professor Jacob Boll, an able Swiss zoölogist and geologist, in 1875–1880 conducted a series of explorations in Texas and published a few papers upon its geology.[1] He, with Mr. Cummins, also collected vertebrate fossils for Professor Cope. His writings were only the introduction to what promised to be valuable original contributions to the geology of Texas; but the strange fatality that has so often interposed a barrier to the completion of all thorough work in this State intervened, and he died in the field in the summer of 1880.

Walter P. Jenney contributed a short but valuable article upon the geology of the trans-Pecos region.[2]

W. H. Adams published an important paper in which he makes some generalizations concerning the coal bearing strata of the Rio Grande region.[3] His deductions concerning the age of the strata at Eagle Pass, Tex., are erroneous and misleading in that he makes it Triassic—from the lithologic appearances and from the occurrence of an ammonite resembling the genus *Ceratites*, when in reality it is the very latest of the Cretaceous, as may be seen by material in the National Museum.

Dr. R. H. Loughridge prepared for the Tenth Census a brief but valuable paper[4] on the geologic features of the State. This may be classed as one of the most important contributions to the general topography and the geology of Texas. It is accompanied by maps showing the distribution of soils &c. and by a brief geologic discussion of the whole region. It contains a comprehensive statement of the areal distribution of the geologic formations and is by far the best general paper upon the subject thus far written. Much detail is given concerning the hitherto indefinite boundary between the Tertiary and the Cretaceous, which Dr. Loughridge deflects too much to the westward south of San Antonio. He notes the occurrence of the Ripley group of the Cretaceous near Terrell, Kaufman County, and gives a list of its fossils. He also describes the character of the rotten limestone as it occurs near Clarksville, but erroneously includes in this formation the several distinct prairie regions of Central Texas. He uses Dr. B. F. Shumard's section, but his own observations are not altogether in harmony therewith. The work is chiefly valuable for the topographic information concerning the State.

[1] "Texas in its geognostic and agricultural aspect," American Naturalist, pp. 375–384, June, 1879; "Geological examinations in Texas," American Naturalist, Vol. XIV, pp. 684–686, September, 1880.

[2] "Notes on the geology of Western Texas, near the thirty-second parallel," by Walter P. Jenney, Am. Jour. Sci., 3d ser., Vol. II, pp. 25–28, 1874.

[3] "Coals in Mexico, Santa Rosa district," Trans. Am. Inst. Min. Eng., Vol. X, pp. 270, 271, 1881–'82.

[4] "Report on the cotton production of the State of Texas, with a discussion of the general agricultural features of the State," Tenth Census of the United States, Vol. *V, pp. 653–831*, 1884.

A. R. Roessler was the original topographer of the Shumard survey, and thus acquired a fund of geographic knowledge with which he has favored the public through the medium of several maps. One of these, printed in 1874, is by far the best contribution to a knowledge of the general surface features of the State. Mr. Roessler has published a series of county maps, giving colored areas to represent the geologic formations, but these maps are not entirely trustworthy. Mr. Roessler has also contributed several articles on the local geology.

Dr. V. Havard, U. S. A., made a most valuable contribution to the knowledge of the general topographic features of the State during 1885. Although the work[1] is primarily botanic, these topographic descriptions of a region about which so little has heretofore been known are important and far more extensive than those in some of the works giving geologic titles.

James P. Kimball, Ph. D., in an article on the geology of Western Texas,[2] discusses the orologic and paleontologic relations of the trans-Pecos country and corrects several errors in the writings of earlier travelers. He describes the peculiar metamorphic formation capping the Cretaceous strata of the region, termed *cantera*, and shows its local variations. The extension of the Texas Cretaceous formation into Mexico is also described. It is one of the most valuable of the very few articles on the region of which it treats.

Charles D. Walcott is the only representative of the scientific corps of the U. S. Geological Survey who has as yet published any results upon the Texas region founded upon personal observation. He visited the Paleozoic rocks of Central Texas in 1884 and published a short paper on them the same year, entitled "Notes on Paleozoic rocks of Central Texas."[3] This article, although brief, ranks in the same category of original investigation as the works of Shumard and Roemer. It contains the following results: Additional data on the Potsdam section and fauna; the Silurian section and fauna; the geologic relations of what has long been known as the Archaic region and its first reference to the Cambrian; and the determination of the age of the granite of Burnet County.

There are several writings upon Texas geology by gentlemen who have not visited the State that deserve mention. Of this number, few have dealt with other than isolated paleontologic descriptions of fossils, and it is of the latter class that it is proper to insert here a few remarks. Paleontology as a science is inseparable from stratigraphy. When they are divorced, paleontology becomes a misnomer for what more

[1] "Report on the flora of Western and Southern Texas," Proc. U. S. Nat. Mus., Vol. VIII (1885), Nos. 29–30, pp. 449–533, Washington, 1885.

[2] "Notes on the geology of Western Texas and of Chihuahua, Mexico," by James P. Kimball, Ph. D., Am. Jour. Sci., 2d ser., Vol. XLVIII, p. 379, 1869.

[3] Am. Jour. Sci., 3d ser., Vol. XXXVIII, pp. 431–433, 1884.

properly deserves the title of systematic or descriptive zoölogy. It is to be regretted that only three invertebrate paleontologists—Drs. Ferdinand Roemer, Benjamin F. Shumard, and C. D. Walcott—have visited the State.[1] The innumerable descriptions of new species of "Cretaceous" and "Tertiary" fossils from Texas that have adorned the annals of the scientific literature of our country for many years will have little value to science until the fossils are studied upon the ground and their proper stratigraphic position is ascertained.[2]

Dr. Samuel George Morton[3] was the first to make allusion to the Cretaceous strata of Texas. He describes, from the "Calcareous platform of Red River," the fossil *Gryphœa Pitcheri*, now accepted as the most characteristic fossil of the typical Texas Cretaceous. This locality, we can only surmise, was the same as that now called the Staked Plains region of Texas. The specimens were collected by Army officers.

F. B. Meek has contributed very little to the number of new species from Texas, but he has made an earnest endeavor to correlate the Cretaceous strata of Texas with those of the other kindred areas of this country.[4]

Dr. C. A. White has not at this date (December 31, 1885) visited the State, but he has published several papers on the paleontology of Texas, as well as figured many of the species described, but not illustrated, by Dr. Shumard. He has also figured and described several new and distinct species and printed lists of fauna from characteristic localities.[5]

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[1] Since writing the above, Mr. T. A. Aldrich, Dr. C. A. White, and others have done some valuable work in Texas.

[2] "Descriptions of new Lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils collected in Nebraska by the exploring expedition under the command of Capt. Wm. F. Raynolds, U. S. Topographical Engineers, with some remarks on the rocks from which they were obtained," Proc. Acad. Nat. Sci. Phila., Vol. XIII, pp. 415–447, 1861.

[3] Synopsis of the Organic Remains of the Cretaceous Group of the United States, by Samuel George Morton, M. D., Philadelphia, 1834.

[4] A Report on the Invertebrate Cretaceous and Tertiary Fossils of the Upper Missouri Country, by F. B. Meek. Report of the U. S. Geological Survey of the Territories. F. V. Hayden, U. S. Geologist in Charge, Vol. IX, Washington, 1876.

[5] Dr. White's writings on Texas geology are here given for the convenience of those who may be interested, because they are not noted in the existing paleontologic check lists, which were printed before his articles were written:

"Report on the paleontological field work for the season of 1877," Eleventh Annual Report of the U. S. Geol. and Geog. Surv. Terr., for 1877, pp. 159–320, 1879. Describes several new species of fossils from the Cretaceous strata of Texas.

"Descriptions of new Cretaceous fossils from Kansas and Texas," Proceedings of the U. S. National Museum for 1879, Vol. II, pp. 292–298.

"Report upon the Invertebrate Fossils collected in Portions of Nevada, Utah, Colorado, New Mexico, and Arizona, by Parties of the Expeditions of 1871, 1872, 1873, and 1874," in Report upon the Geographical and Geological Explorations and Surveys West of the One Hundredth Meridian, in charge of First Lieut. Geo. M. Wheeler,

Prof. Angelo Heilprin has published a valuable compilation of the observations that have been made upon the Tertiary geology of the State in his work entitled Contributions to the Tertiary Geology and Paleontology of the United States, printed at Philadelphia in 1884. Besides being a compilation of previous research, the observations and the deductions of Professor Heilprin therein expressed are of great value. He has, besides, described several species from the Tertiary of the State.

The writings of Messrs. James Hall, Conrad, and Gabb have been referred to in the preceding pages in connection with the expeditions upon which the fossils and other specimens were collected. They also made a few individual contributions. The true horizon of the species cannot be known until further stratigraphic observations are made.

WORK OF THE U. S. GEOLOGICAL SURVEY.

This narration of the geologic work accomplished in Texas practically closes at the date when the U. S. Geological Survey was authorized to carry its work into the States (1884), although I have included some work done by C. D. Walcott, thus extending the narrative to December 31, 1885. The date at which the U. S. Geological Survey was enabled to extend its operations into the States is one of the most important in our scientific history, and to the State of Texas it will prove of especial consequence. The era of hasty reconnaissance and poorly published results may be considered ended and the work

Corps of Engineers, U. S. Army, Vol. IV, Part I, Paleontology, pp. 1–219. 4°. Washington, 1875. Gives lists of fossils from Cretaceous localities in Texas.

"Conditions of preservation of invertebrate fossils," in Bull. U. S. Geological and Geographical Survey of the Territories, Vol. V, article VII. Describes characteristic condition of preservation of fossils from the Cretaceous rocks of Texas. Washington 1879.

"Descriptions of new Cretaceous invertebrate fossils from Kansas and Texas." Proc. U. S. National Museum, Vol. II, pp. 292–298, Plates I–IV.

"Contributions to invertebrate paleontology No. 1: Cretaceous fossils of the Western States and Territories," in Eleventh Annual Report U. S. Geological and Geographical Survey of the Territories [for the year 1877], pp. 273–319, Plates I–IX. Washington, 1879. Describes a few fossils from the Cretaceous of Texas.

"Contributions to invertebrate paleontology No. 2: Cretaceous fossils from the Western States and Territories," in Twelfth Annual Report of the United States Geological and Geographical Survey of the Territories [for the year 1878], pp. 1–38; Appendix, pp. 38, 39, Plates XI–XVII. Washington, 1883.

Notes on the Mesozoic and Cenozoic Paleontology of California. U. S. Geological Survey Bulletin 15, Washington, 1885. Describes the westward extension of fossils common to Texas.

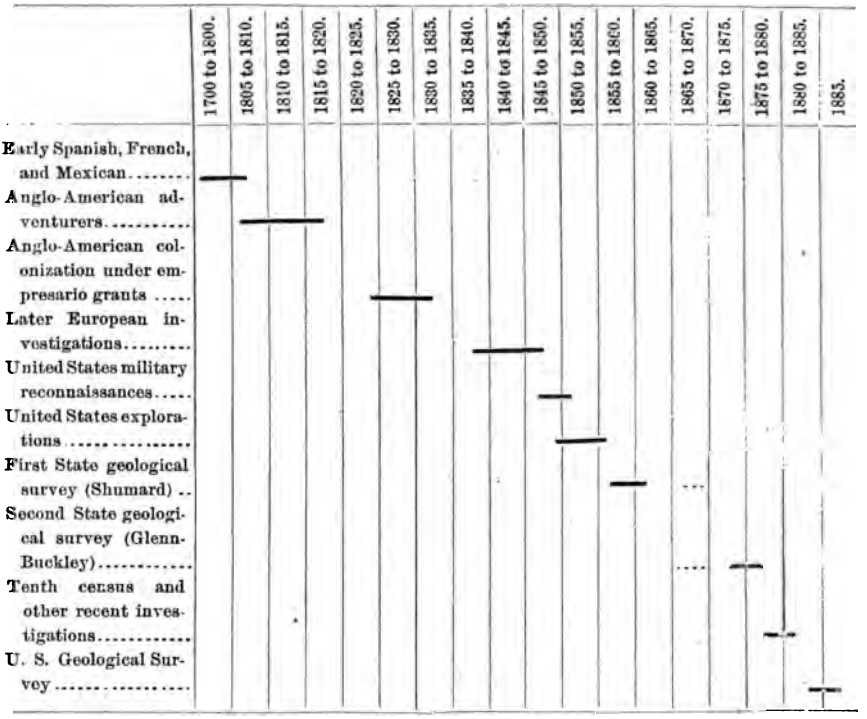
"On Mesozoic Fossils. Description of certain aberrant forms of the Chamidæ from the Cretaceous rocks of Texas." U. S. Geological Survey Bulletin No. 4, Washington, 1884.

"A review of the fossil Ostreidæ of North America; and a comparison of the fossil with the living forms," in Fourth Annual Report of the U. S. Geological Survey, pp. 273–333, Plates XXXIV–LXXXII, Washington, 1884.

of thorough scientific exploration will be continued under more adequate methods. Already several sheets of the topographic map have been issued.[1]

SUCCESSION OF SCIENTIFIC EXPLORATIONS.

Diagram of succession of eras of scientific explorations in Texas.



[1] Respecting the methods of the U. S. Geological Survey in making maps, see Annuaire géologique universel, tome II, 2e partie, appendice, Paris, 1886: Méthodes de cartographie géologique employées par l'United States Geological Survey, presented at Berlin by W J McGee.

II. SUMMARY OF RESULTS.

TOPOGRAPHY.

It is plain that the scientific investigations heretofore made in the State of Texas have been elementary and fragmentary in character. Especially does this become apparent when we contrast the small amount of work done with the size of the State. For instance, strata of the Cretaceous period are found near both Texarkana and El Paso, although these cities are nearly eight hundred miles apart; but not a line is published noting a single dissemblance between the stratigraphic and the zoölogic features of this formation between these two places, except the confessedly limited observations of Roemer, Marcou, Shumard, Schott, Parry, and Marcy. The contributions of others, especially those of a paleontologic nature, will remain unavailable until further verification. Many of the paleontologic descriptions of species are even without any locality, much less any detailed assignment to a stratigraphic horizon, and nothing has been done in the direction of tracing faunal or specific range and variation. For the stratigraphy even less can be said than for the paleontology, although a few sections of great value have been presented. It must be said, however, that stratigraphic work has been peculiarly neglected in this State. Even Roemer's great work, the best ever printed on the geology of Texas, does not give a single stratigraphic section, and we find extending through its otherwise almost incomparable pages a fundamental stratigraphic error whereby the value of the whole is impaired.[1]

The topography of the State, excepting the limited portion covered by the recent operations of the U. S. Geological Survey, is poorly delineated. The slope of the surface, the directions of the streams, and the principal forest regions were known in a general way to the Spaniards long before the present century and were crudely delineated by Humboldt in 1804. The development of detail and the delineation of these features upon successive maps until the present time have been successively expanded and recorded by Kennedy, Roemer, and other individuals, the various land locating parties, railroad surveys, and military expeditions. The finer points of inland topography,[2]

[1] Roemer thought that the Cretaceous formations at the foot of the highlands between New Braunfels extended beneath instead of resting unconformably upon them.

[2] The U. S. Coast and Geodetic Survey has carried its work along the immediate coast line of the State.

such as triangulation, determination of altitudes, meandering of streams, &c., have never been attempted until the recent operations by the U. S. Geological Survey, and even the coarser topographic features have not been correctly presented. For instance, it is utterly impossible at this writing to obtain an idea of the trans-Pecos mountain systems, and no map makes a distinction between the hills or buttes east of that region and true disturbed mountain ranges. The chief defect in our topographic knowledge of the State is incident to the fragmentary manner in which the same has been collected, no attempt having ever been made by the State of Texas to make a systematic map of its territory.[1]

The most accurate description of the topographic features is that of Loughridge, 1884, but even this fails to classify the natural divisions in a comprehensive manner. He says:[2]

> In the State of Texas we find combined a great diversity in both soil and topography; * * * in topography, from the extreme of low and flat prairie lands and a very little marsh along the coast, by gradual transitions and elevations, to the chains and peaks of mountains on the far west [southwest], whose summits are 5,000 feet or more above the sea.
>
> * * * * * * *
>
> Several of the great agricultural regions that form so prominent a feature in the other Southern States have their termini in Texas, and are cut off on the southwest either by the prairies of the coast or by the great mesquite and cactus chaparral prairies of the Rio Grande region, or they abut against the eastern bluffs of the plains.
>
> The coast of Texas * * * is here bordered by an almost continuous chain of islands and peninsulas (the latter having the same trend as the islands). * * * The large estuaries that have been formed at the mouths of the streams, except the Sabine, the Rio Grande, and those of the Brazos section, form another feature peculiar to the Texas coast. The border lands of these estuaries are usually high, their almost vertical clay bluffs being washed by the waters of the bay, and the open prairies of the uplands often extend to their very edge.
>
> Mr. Gannett estimates the water area of the coast, bays, gulfs, &c., to be 2,510 square miles and that of the rivers and lesser streams at about 800 square miles.
>
> A general view of the State, as presented in two cross-sections, presents the following features:
>
> 1. *Along the Louisiana line.*—From the mouth of Sabine River northward we find at first a small area of marsh lands, terminating the marsh region of Louisiana, and not occurring to any extent westward. Passing these, we come to the long-leaf pine flats, extending westward only to the Trinity River, and being also the western ter-

[1] The map representing the physical geography of Texas more minutely than any other is entitled "A. R. Roessler's latest map of the State of Texas, exhibiting mineral and agricultural districts, post-offices and mail routes, railroads projected and finished, timber, prairie swamp lands, &c. Authorities: Official maps of the United States and Texas State General Land Offices, surveys and reconnoissances of the U. S. Coast Survey, the various railroad surveys, U. S. Mexican Boundary Commission Surveys, U. S. Engineer Dept., and other authentic materials, compiled and drawn by M. Y. Mittendorfer, C. E., 1874." Much of the excellent detail of this map was evidently made from data collected by the Shumard survey, of which Mr. Roessler was topographer.

[2] Tenth Census: Report on Cotton Production in the United States. Report on the Cotton Production of the State of Texas, Part I, pp. 653–831.

minus of the belt that extends across all of the Gulf States, the lower part of Florida, and along the Atlantic coast through North Carolina. Its surface in Texas is quite level northward for about 50 miles, when the more undulating or rolling pine hills are reached, which also form a border to the pine flats just mentioned across the southern Gulf States. Thence northward to Red River the country is rolling and hilly, and is covered with oak, hickory, and short-leaf pine—a region that extends eastward through Louisiana, Arkansas, and the northern part of Mississippi into Tennessee. This region passes southwestward, becoming more and more narrow, until it tapers off to a point 100 miles from the Rio Grande, and also includes the belt of the red Tertiary hills of the other States that probably terminates on the southwest in Guadalupe County.

2. *From the coast in a northwest and west direction.*—The mainland coast of Texas presents a very irregular outline, with its many bays, peninsulas, and islands, and but a small proportion of the mainland reaches the waters of the Gulf. As before stated, there is scarcely any marsh land on the coast west of the Sabine marshes.

For a distance of from 50 to 100 miles inland from the coast the country is very level, with open prairies, whose continuity is broken only by the timbered streams, with occasional strips or "motts" or clumps of timber, and by the broad and heavily timbered alluvial or "sugar bowl" region of the Brazos.

The rise, slight and very gradual inland from the coast, is almost imperceptible for many miles, when the country becomes undulating and then rolling, and the prairies give way to the more or less broken and hilly oak and pine uplands, which cover all of the northeastern part of the State, as already mentioned. The country rises rapidly to the north and northwest, reaching an elevation of several hundred feet along the western edge of the timbered region, and is interspersed throughout with small "brown loam prairies." Leaving the timber lands and continuing northwest we find a region of "black waxy prairies," underlaid by the Cretaceous "rotten limestone," extending southwest to San Antonio and thence west to the foot of the plains. Northward this region passes through the southern part of the Indian Territory into Arkansas. These prairies are at first, on the east, rather level, or at most undulating, with an altitude of 500 or 600 feet, but westward become more rolling, hilly, and broken, until finally, on their western limits, high and bald hills and peaks stand out in bold relief at an elevation of nearly 1,000 feet above the sea. The monotony of these interior prairies is broken by the timbered streams and on the north by the wide belt of "lower cross timbers," which reaches from the Red River to the Brazos in an almost due south course. Otherwise there is very little timber to be seen.

At the western edge of the northern half of the black prairie region there is another belt of cross timbers,[1] interspersed with small, black, Cretaceous prairies, very irregular in outline and in width, and beyond it is the broad red-loam and partly timbered region, comprising high ridges, mesquite prairie valleys, and broad tablelands, the country gradually rising to the foot of the high plateau of the Llano Estacado, several thousand feet above the level of the sea. This region terminates on the southwest against the bluffs of the plains south of the Llano Estacado, and a large area penetrates southeastwardly almost across the black prairie region.

On the northwest there is a large, extensive region, lying wedge shaped, with its point south, between the red loam lands and the Llano Estacado, and comprising the great gypsum lands of the State, with high and rolling prairies, whose uplands are largely destitute of timber.

To the westward the broad, level, and bare plains of the Llano Estacado occupy a terrace with abrupt bluffs on the north, some 200 feet above these regions, and with a gentle rise pass out of the State into New Mexico on the west and to the mountains on the southwest. Deep cañons have been cut into the eastern part of this plateau

[1] Mr. Loughridge places this edge of the black prairie too far west. It ends at the eastern edge of the lower cross timbers.

by the headwaters of the large rivers of the State, but to the west there is only a vast, treeless plain, more or less undulating, with a few low but prominent sand hills and ridges.

On the extreme west, between the Pecos and the Rio Grande, the country reaches its maximum height, with several chains of almost treeless mountains rising several thousand feet above the general level, and separated from each other by broad and level plains 20 or 30 miles in width and almost destitute of vegetation. These mountain ranges enter the State from New Mexico. Southward the plains extend along the Rio Grande to a point a little south of its junction with the Pecos. Thence to the Gulf are broad and high prairies, broken by deep arroyos or ravines, and with little growth other than occasional live oak trees and great chaparrals or thickets of thorny shrubs.

CLASSIFICATION OF TOPOGRAPHY OF TEXAS.

For convenience of discussion I broadly classify the general topography of Texas as follows:

First. The coastal plain, representing the continuation of the topographic features of the other Gulf States, so far as they represent the sedimentation of the former waters of the Upper Cretaceous outlines of the Gulf of Mexico, the topographic and geologic boundaries coinciding. In Texas this approximately coincides with a line drawn concentric with the Gulf coast about 200 miles inland.

Second. The black prairie region, a triangular area immediately succeeding the foregoing to the west. It is also a southern continuation of similar topographic and geologic features of Arkansas, Mississippi, and Alabama. Its western boundary extends from Eagle Pass via Austin to Denison, on Red River. It is a level or gently undulating prairie, with a general slope to the southeast and an altitude of from 500 to 750 feet. The underlying strata are uniformly Cretaceous and of a horizon that will be described elsewhere.

Third. The central or denuded region, embracing all the country between the escarpment of the plains and the black prairie region and north of the hydrographic basin of the Colorado. This region comprises a number of geologic formations and is between 600 and 2,000 feet in altitude.

Fourth. The plateau region, comprising the Llano Estacado. It is a continuation from the northward of the topographic and geologic features of the great plains along the eastern slope of the Rocky Mountains.

Fifth. The mountainous or trans-Pecos region. This consists of the country in Texas and Northern Mexico adjacent to the disturbed area of the southern or southeasterly prolongation of the Rocky Mountains. It is chiefly west of the Pecos, in Texas, but crosses into Mexico west of that river, again recrosses the Rio Grande east of it near Eagle Pass, and continues until a few miles south of Laredo.

Each of the areas has a well marked individuality, although the boundaries between them cannot always be closely defined.

Chart illustrating the progressive classification of the topographic features of Texas.

Kennedy, 1841.	Ferd. von Roemer, 1848.	R. H. Loughridge, 1884.	Classification used in this work.	
The level region.	The level region (niedriges, flaches Land).	Southern and coast prairies. Gray silt and pine lands. Sea marsh. Oak, hickory, and pine region. Brazos delta and other alluvial lands.	(1) The coastal plain. Pine lands. Pine, oak, and hickory lands. Prairies of East Texas. Coast alluvium. Southwestern prairies.	Continuation of salient topographic features of coast plain of Louisiana, Arkansas, Mississippi, Alabama, &c.
Rolling or undulating region.	Hill land, or rolling or undulating region (sanftwelliges Hügelland).		(2) Black prairie region.	Continuation of black prairie regions of same States, except Louisiana.
Mountainous region.	Highlands (das zum Theil felsige Hochland).	Central black prairie region. Cross timbers. Sand hills and metamorphic lands of Central Texas. Northwestern red loam prairies and timber lands. Gypsum prairie region.	(3) Central or denuded region. Cross timbers. Coal Measures. Grand prairie. Butte districts. Hamilton County prairie. Granite region. Gypsum lands. Red prairies.	Peculiar to Central Texas and southern part of Indian Territory. Terminates west of San Antonio before reaching Rio Grande.
	Steppen-Lande.	Llano Estacado (table lands and sand hills).	(4) Plateau or Staked Plains region.	Southern continuation of Great Plains at eastern foot of Rocky Mountains, British America to Southern Texas.
		Plains with granitic mountains and probably "sand" desert of Rio Grande.	(5) Mountainous or trans-Pecos region. West of Pecos River and Lower Rio Grande, between Eagle Pass and Laredo.	Southeastward deflection and continuation of mountain region of New Mexico.

HISTORIC GEOLOGY AND STRATIGRAPHY.

In the following table are given, from the writings already mentioned, the members of the geologic series that have been reported from Texas. The authority for some of these groups is slight and untrustworthy, but

nevertheless they have been thus published. Many of the subdivisions are synonyms of different authors, which will require extensive field work for positive identification and correlation.

Geologic formations reputed to occur in the State of Texas, with authorities.

Era.	Period.	Subperiod.	Local formations.	Reported occurrence in topographic area —
Cenozoic.	Quaternary	Recent[1]	Alluvium[1]	1
			Diluvium[1]	1
	Tertiary.		Grand Gulf[5]	1
			Mauvaises Terres[4]	1
			Vicksburg[7]	1
			Claiborne[1]	
Mesozoic.	Cretaceous.	Senonian[1]	*Laramie*,[6] Eolignitic[7]	1 and 2
			Kreide des Hochlandes[1]	2
			Comanche Peak group[4]	3
		Senonian[2]	Washita Limestone[2, 3]	3
		Turonian[1]	Kreide am Fusse des Hochlandes[1]	2
			Ripley group[4, 6], Austin Limestone	2
		Greensand[3]	Rotten Limestone[5]	2
			Dakota Sandstone[4]	2 or 3
		Neocomian[3]	Washita Limestone[3]	3
			Comanche Peak group[3]	3
	Triassic and Jurassic.	*Jurassic*[3]	*Washita Limestone*[3]	3
			Comanche Peak group[3]	3
			Staked Plains[3]	
		Triassic[3]	Gypsum region[3]	3 and 4
		Jura-Trias[2]	*Red beds*[6]	3
		Permian[2, 6]	*Upper Carboniferous*[2]	
Paleozoic.	Carboniferous.	Permo-Carboniferous	Upper Carboniferous[8]	3
		Permian[2, 6]	Trans-Pecos region	5
		Upper Carboniferous.	Central region[9]; Trans-Pecos region[8]	3 and 5
		Sub-Carboniferous[9]	*Brazos Coal Field*[9]	3
	Devonian.	*Devonian*[9]	Central region	3
	Lower Silurian.	Cincinnati[3]		3 and 5
		Chazy[3]		5
		Calciferous[10]		3 and 5
	Cambrian.	Potsdam[10]		3 and 5
	Pre-Cambrian.	Llano[10]		3
		Archean[1]		
		Azoic[1]		

NOTE.—Authorities: [1] Ferdinand Roemer; [2] G. G. Shumard; [3] Jules Marcou; [4] B. F. Shumard; [5] R. H. Loughridge; [6] E. D. Cope; [7] Angelo Heilprin; [8] James Hall; [9] C. A. Ashburner; [10] C. D. Walcott. Names of local formations, in italic, as applied by the writers referred to are no longer accepted.

SO-CALLED ARCHEAN AND EARLIER PALEOZOIC STRATA.

The older rocks of the geologic series are found in both the central and the trans-Pecos area, but they have been studied chiefly in the former and little or nothing is known of their exact occurrence in the latter.

A few miles south of the present geographic center of the State, in the counties of Mason, Llano, Burnet, and San Saba, is an outcrop of so-called Archean and earlier Paleozoic rock. This region was known to the Spaniards and was evidently considered by them of much mineral importance. Kennedy[1] first intimated its geologic age and Roemer was the first to give an intelligent description of it. Dr. B. F. Shumard confirmed Roemer's work, but its true stratigraphic relations were not understood until lately studied by C. D. Walcott, of the U. S. Geological Survey. Of these Paleozoic strata Mr. Walcott says:[2]

> At all localities where the base of the Potsdam was observed it rests *unconformably* on a great formation that is stratigraphically the equivalent of Powell's Grand Cañon series (Grand Cañon and Chuar groups).[3] In the Grand Cañon of the Colorado the latter are overlaid by the Tonto group, a series of rocks in both lithologic and paleontologic characters singularly like the Texas Potsdam group.
>
> For this series of pre-Potsdam strata the local name of Llano group is proposed, from the best exposures of the group occurring in the county of Llano. Outcrops also occur in Burnet, Mason, San Saba, Blanco, and Gillespie Counties.

Mr. Walcott speaks of "extrusions of granite at or near the close of the erosion of the Llano group and before the deposition of the Potsdam," and says further: "It is to this age that the great masses of granite observed in Western Burnet and all through Llano County belong." The early students of these strata supposed that the outcrops of eruptive and granitic rocks were Azoic or Archean, and that they were the base of the entire series. Mr. Walcott showed that there are no rocks there exposed of the undoubted Archean and that the granites before referred to that era were not fundamental, but extrusive, and since his deductions are based upon more careful stratigraphic study

[1] Texas: The Rise, Progress, and Prospects of the Republic of Texas, Vol. I, pp. 114 et seq.

[2] "Note on Paleozoic rocks of Central Texas," Am. Jour. Sci., 3d ser., Vol. XXVIII, pp. 431–433, 1884.

[3] In a later paper Mr. Walcott refers these groups to the Keweenawan, and says: "The Keweenaw system is here used to include the Keweenaw series of the Lake Superior region, the Llano series of Texas, and the Chuar and Grand Cañon series of the Grand Cañon of the Colorado, Arizona, and is considered of equal value with the Cambrian, Lower Silurian (Ordovician), Upper Silurian, and other systems of the Paleozoic rather than the Archean. It may be that the Keweenaw and Grand Cañon series belong to distinct systems of strata, but until this is proven I prefer to provisionally refer them to the pre-Cambrian, post-Huronian system. I think the Grand Cañon and Llano strata belong to one system."—"Classification of the Cambrian System of North America," Am. Jour. Sci., 3d ser., Vol. XXXII, pp. 138–157, 1886. The extract forms a note on p. 153.

than those of his predecessors they are more trustworthy. According to him these earlier Paleozoic rocks consist of the following:

(1) *The Llano group.*—Alternating beds of shale, sandy shale, sandstone, limestone, and schists; thickness not determined, but probably over 2,000 feet; continuity broken by extrusive sheets of granite of pre-Potsdam origin; stratification disturbed by movement at the close of the Paleozoic, whereby the dip increases from 10° at the north end of the ridge to 40° at the south end; strike, eastward; unfossiliferous.

(2) *The Potsdam group.*[1]—Consists of massive sandstone, limestone, and Potsdam sandstone, marked by abundant Upper Cambrian (Potsdam) fauna.

(3) *The Calciferous group.*—Lower Silurian, with its characteristic fauna.

(4) *The Carboniferous group*, which was not here studied in detail.

From the observations of Mr. Walcott it is evident (*a*) that there are no Archean exposures yet known in Central Texas (this being the only Paleozoic region yet studied); (*b*) that the pre-Potsdam, the Silurian, and the Carboniferous groups are represented; (*c*) that the Devonian is absent; (*d*) that the age of the so-called Archean granites is Paleozoic; (*e*) that there were two well marked epochs of disturbance, one after the close of the sedimentation of the Llano group and the other near the close of the Paleozoic; (*f*) that the Llano group is the equivalent of the Grand Cañon and Chuar groups of Powell, and hence at the time of their deposition the sedimentation was continuous to the westward of the Grand Cañon.

The Paleozoic strata, excepting the Carboniferous, have only a limited outcrop in Texas, so far as has been discovered. The disturbed areas of the Wichita Mountains, in the southwestern corner of Indian Territory, theoretically present every favorable condition for the presence of similar exposures, but no evidence of their existence has been reported, except the similarity of their granitic structure.[2]

The large trans-Pecos disturbed mountain area also presents exposures of early Paleozoic strata, as has been reported by G. G. Shumard, Jenney, Kimball, and members of various government expeditions. Concerning the occurrence of the Lower Silurian in that region, Dr. G. G. Shumard said of the valley of the Rio Grande above El Paso:[3]

> The limestone of the Lower Silurian system is seen strongly upheaved against the western base until we reach a point ten or eleven miles north of t he place where it was first discovered, when it disappears and is succeeded by strata of the Carboniferous system, which are exposed in places to the thickness of about three hundred feet. Against the western declivity, El Paso Mountains, the limestone strata are strongly upheaved, and where it is in immediate contact with the eruptive strata it

[1] Well described by B. F. Shumard, Am. Jour. Sci., 2d ser., Vol. XXXII, pp. 213–221, 1861.

[2] See numerous references in Exploration of the Red River of Louisiana in the year *1852*, by Randolph B. Marcy, 1854.

[3] *Trans. Acad. Sci. St.* Louis, Vol. I, p. 288.

is highly metamorphosed. I was much interested by finding here, near the base of the exposure, well marked strata of the inferior Silurian system, corresponding in age to the blue limestone of Cincinnati and the Hudson River group of the New York series. The following fossils were procured from these beds: *Orthis testudinaria* Dalman, *O. occidentalis* Hall, *Rhynchonella capax* Conrad, *Rhynchonella* (a species of the blue limestone of Cincinnati), *Streptalasma corniculaf* Hall, and columns of crinoids.

Every reason exists for the supposition that the Cambrian strata are exposed there, but no surveys of the region have been made.[1] Walter P. Jenney[2] gives a section of the rocks north of El Paso, two miles, in the Organ Mountains, and recognizes there the following formations in descending series: Carboniferous, or Niagara, deposited unconformably upon a coarse conglomerate, which he thinks probably equivalent to the Oneida conglomerate of New York; gray limestone of the Hudson period; black limestone representing the Trenton, the Chazy, the Calciferous sand rock, and the Potsdam. He finds similar rocks in the Hueco Mountains, twenty miles north of the Organ Mountains, and concludes that "the greater part of the Upper Silurian and the whole of the Devonian periods are unrepresented in the rocks of Western Texas." He notes an immense development of the Carboniferous strata in the Sacramento and the Guadalupe Mountains, and of syenite at Los Cornudos. He also gives a section of the Llano Estacado as exposed at Castle Cañon and affirms their Cretaceous age; the highest he makes the Caprina Limestone of Shumard. He erroneously concludes that the denuded Cretaceous buttes east of the plains almost as far as Austin "were islands in the sea which produced the denudation, their tops showing no evidence of having ever been submerged, and in some cases wave worn cavities extend at the same height along their sides.[3]

CARBONIFEROUS SYSTEM.

The absence of the Devonian from the stratigraphic series in Texas has been noted, first by Roemer and later by Walcott and others. Dr. S. B. Buckley asserts in one of his reports that Dr. B. F. Shumard had previously announced the occurrence of the Devonian strata in Texas, but I have failed to find such a statement in any of Shumard's publications. If the Devonian is not represented, then it is evident that the Carboniferous strata are next in order after the Silurian. This fact was demonstrated by Roemer, who first noted the positive occurrence of the Carboniferous strata in Texas resting upon the older rocks along the San Saba River. He formed no idea of the extent of these rocks, however, and was not aware of their great development northward.

It is now evident that there are two widely separated areas of the Carboniferous strata in Texas, each of which has well marked individ-

[1] C. H. Hitchcock's geological map of the United States gives a large Cambrian area in the trans-Pecos region of Texas.

[2] "Notes on the geology of Western Texas near the thirty-second parallel, by Walter P. Jenney," Am. Jour. Sci., 3d ser., Vol. VII, pp. 25–28, 1874.

[3] These buttes are the remnants of subaërial erosion entirely.

uality. These I will describe separately under the names of the Central Carboniferous area and the trans-Pecos Carboniferous area.

The central Carboniferous area.—This is a comparatively narrow but elongated area of exposures, continuing from Indian Territory, between the ninety-eighth and the one hundredth meridian. Its eastern border is limited by the upper cross timbers. The extent of this area in Texas is some two hundred miles north and south between the Colorado River and the Red River. Geologically it may be said to extend along the axis of greatest denudation from the point of greatest disturbance, in Llano County, to the connection with the great Missouri coal field in Indian Territory. The latitudinal development of exposures is of varying width, owing to the irregularity of the denudation of the superincumbent Cretaceous strata, and other causes. The exposure widens, however, towards its southern base. At no place does it exceed one hundred miles in width. Exposures have been noticed in Young, Jack, Montague, Stephens, Shackelford, Palo Pinto, Baylor, Wise, Coleman, Brown, Comanche, Runnels, McCulloch, Tom Green, and San Saba Counties. Its exact boundaries are unknown. The exposures of these strata are the result of denudation of the Cretaceous, which once covered them entirely, and I have noted on the preceding pages the history of the discovery of this area. Dr. Roemer's determinations were based upon stratigraphic and paleontologic data and he did not discover the existence of bituminous coal. Various Army officers have noted the occurrence of coal to the northward, but it was first clearly described by Dr. G. G. Shumard in his remarks accompanying Marcy's report on the exploration of the Red River of Louisiana (1854). Mr. Jules Marcou the next year contributed much toward a knowledge of the geologic and stratigraphic relations and in subsequent maps intimated the continuity of the Young and San Saba County areas. Dr. B. F. Shumard, as State geologist (1858), was the first to demonstrate in the field the actual continuity of the two regions, concerning which he contributed nearly all we know. The local occurrence and the general extent having been proved by these earlier reconnaissances, there still remains much to find out concerning nearly all the geologic data of the region. Prof. C. A. Ashburner, of Pennsylvania, in a study of the northern portion of these coal fields in 1879, made the following section of the strata in the vicinity of Fort Belknap, Young County:[1]

	Feet.
Sandstone and conglomerate	40
Coal	1
Sandstone and shale	12
Coal	1
Sandstone and shale with occasional beds of limestone	15
Belknap coal bed	2½ to 4
Sandstone and shale	12

[1] "Brazos coal-field, Texas," Trans. Am. Inst. Mining Eng., Vol. IX, p. 497, 1880–'81.

	Feet.
Coal	1
Gray slate	10
Sandstone	25
Brazos coal bed	4 to 6
Gray limestone	150

From the above section he made the following deductions:

This succession of the strata is not unlike that to be found in many localities where the Carboniferous rocks are found in the Middle States. It seems to point clearly to the conclusion that the top sandstone and conglomerate is the representative of the Carboniferous conglomerate or Millstone Grit; that the limestone is the sub-Carboniferous or Mountain limestone, known generally throughout the Mississippi Valley as the Saint Louis or Chester limestone, and that the included Coal Measures are really subconglomerate.

His final conclusions are summed up at the close of the paper just quoted as follows:

The Brazos coal field is the southwestern limit of the Missourian or fourth bituminous coal basin of the United States. The Coal Measures of Stephens and Young Counties belong to the Carboniferous age. The coal strata proper are 85 feet thick, and are included between an upper sandstone and a conglomerate, representative of the Millstone Grit or Pottsville conglomerate No. 12 of the Pennsylvania series, and a lower gray limestone, representative of the Mountain limestone or Chester and Saint Louis limestone of the Mississippi Valley. The coal strata contain two coal beds of workable thickness. The upper bed, named Belknap, ranges from 2½ to 4 feet; and the lower, named Brazos, from 4 to 6 feet. The coals are high in ash and sulphur, but have never been thoroughly tested. The Brazos bed underlies a great area and will no doubt prove to be a valuable commercial coal in some localities.

The southern portion of these central exposures has not been so well studied, and we have nothing but analogy from which to infer[1] that there they are practically the same, except that the carbonaceous layers in that region become almost if not quite extinct.

Dr. Buckley reports coal from this southern region, but he was not an authority on the subject of coals, not having had a clear idea of the distinction between the true coals of the Carboniferous and later Western formations and the lignite of the Mississippi area, which is known to occur in near proximity.[2]

The trans-Pecos Carboniferous area.—Along the disturbed axes of the trans-Pecos mountainous region extensive beds of limestone have been frequently noted by reconnoitering parties. The knowledge of the topography of this area is very limited, and, this being true, it is evident that little can be known of the distribution of the geologic formations. That Carboniferous rocks occur in this region has been recorded by many observers, but very little is yet known of their true nature, except that they usually consist of massive limestone, are barren of coal seams, and that they occur along the disturbed and denuded mountain re-

[1] "Brazos coal-field, Texas," Trans. Am. Inst. Mining Eng., Vol. IX, p. 506, 1880–'81.

[2] See discussion of coals, First Report of Progress, Geological and Agricultural Survey of Texas, B. F. Shumard, State geologist, Austin, 1865.

gions. These rocks are probably a continuation of the New Mexican Carboniferous, as has been noted by Marcou and others.[1]

Two expeditions have supplied some details concerning this region, but our knowledge of it is still very general. One expedition recorded the Carboniferous as it occurs near the Rio Grande, the other as it occurs approximately along the thirty-second parallel. The observers were Dr. C. C. Parry,[2] of the Mexican boundary survey, and Dr. G. G. Shumard,[3] of Capt. John Pope's expedition for boring artesian wells in the Great Plains. The collections of both of these gentlemen fell into the hands of good geologists, and reports were written upon them by Prof. James Hall[4] and Dr. B. F. Shumard,[5] respectively.

Dr. Parry, in his remarks,[6] gives the following general facts concerning the occurrence of this formation along his line of observation: The first disturbance, traveling westward from San Antonio to El Paso, is Sierra Diablo, or Limpia Range, near Fort Davids. The elevation at Leon Springs, the last point upon the horizontal, undisturbed Cretaceous strata before reaching this range, is some 2,200 feet above San Antonio,[6] giving an average rise of seven feet to the mile and a total elevation above the sea of 2,788 feet.

This range is characterized at nearly all the separate points noticed by Dr. Parry by the presence of igneous rocks accompanied by metamorphic rocks and strata of sedimentary character, which Professor Hall considered to be of the Carboniferous period. The dip varies, but is generally to the southwest. From this range westward to El Paso there are several other mountainous elevations and intervening plains, the former being of the character of the Limpia Range just mentioned and the latter consisting of alluvial deposits, the detritus from the surrounding mountains. At El Paso the character of the region again changes, a greater disturbance being noted. On the Mexican side the various formations, stratified and igneous, are blended and intermixed in great confusion, while on the American side the strata consist of stratified limestone dipping W.SW., in the face of which rest igneous outbursts associated with the disturbed Cretaceous beds.[7] This limestone was determined by Professor Hall to belong to the Carboniferous series, being a continuation of that above noted.

[1] Described in Report U. S. Geog. Surv. West of One Hundredth Meridian, under charge of Capt. G. M. Wheeler, Vol. III, Supplement, Geology.

[2] See Report U. S. and Mexican Boundary Survey, Vol. I, Part II.

[3] See Trans. Acad. Sci. St. Louis, Vols. I and II. Numerous papers by both Dr. G. G. and Dr. B. F. Shumard.

[4] Observations on the Carboniferous limestone of the Boundary Survey collections, and its relations with the Carboniferous limestones of the Mississippi Valley. By James Hall, in Report U. S. and Mex. Bound. Surv., Vol. I, Part II, p. 122.

[5] Trans. Acad. Sci. St. Louis.

[6] Report U. S. and Mexican Boundary Survey, Vol. I, Part II, p. 4.

[7] Ibid., p. 8.

Concerning its age, he said:[1]

The Carboniferous limestone so often mentioned in the preceding pages, and which has been usually referred to in published reports as "Carboniferous limestone" and as Lower Carboniferous limestone, is actually of the same age as the Coal Measures. * * * In all the collections which I have examined from Texas and New Mexico, and from points farther north in the same line, and particularly in the collections made by Captain Stansbury on his route from the Missouri to the Great Salt Lake and in that region, I have never observed fossils which are characteristic of the Lower Carboniferous limestone.[2]

Dr. G. G. Shumard's observations of these strata along the thirty-second parallel agree with those of Parry in general respects. Along this route he repeatedly found exposures of the Carboniferous strata, where he crossed the disturbed mountain chains of the Guadalupe, the Cornudos, the Sierra Alta, the Sierra Hueca, and the El Paso Mountains, respectively. In addition to the features noticed by Parry he observed the Lower Silurian (Cambrian?) underlying the Carboniferous to the north of El Paso and elsewhere.

He noted the following stratigraphic features of the region:

(1) It is underlaid by a granite bearing series (the Llano Group of Walcott?).

(2) The Carboniferous in some places rests conformably upon the Lower Silurian strata.

(3) The Cretaceous rests unconformably upon the Carboniferous.

(4) The Paleozoic strata of the region are greatly disturbed.

(5) The occurrence of characteristic fossils of the Coal Measures proves the age of these strata. Here, however, they were purely marine, the rocks being almost entirely of limestone and the fossils characteristic invertebrates similar to those of the Carboniferous of Missouri and Illinois.

Above these rested a later series, which he and his brother, Dr. Benj. F. Shumard, called the Permian,[3] containing fossils having many characteristics of Permian fossils and similar to the rocks of the same nature reported by Swallow and Horn and by Meek and Hayden in Kansas. Other species were said to be identical with characteristic Permian fossils of England and Russia and many were new to science.

Upon comparison with the Llano County strata, as noted by Roemer, Shumard, Walcott, and others, it will be seen that they have some common features. The distance between these two areas of disturbance, from Llano County to the intersection of the Guadalupe Mountains and the thirty-second parallel of latitude, is 300 miles, and the intervening surface is occupied by nearly horizontal undisturbed series of Mesozoic rocks, which at each place are unconformable with the

[1] Report U. S. and Mex. Bound. Survey, Vol. I, Part II, pp. 122, 123.

[2] This opinion of Professor Hall has been confirmed by observations of the extension of these strata farther north. See U. S. Geog. Surv. West of the One Hundredth Meridian, in charge of Capt. G. M. Wheeler, Vol. III, Supplement, Geology.

[3] Concerning these Permian strata I shall say more in the following pages.

Carboniferous, indicating beyond doubt that there was a period of great disturbance at the close of the Paleozoic.

It is very doubtful whether the Carboniferous strata of this region of the State are of economic value. Coal deposits have been discovered within the past few months very near the region visited by Dr. Shumard,[1] but their horizon is not announced.[2] Coals have also been reported north of El Paso, but their place in the geologic scale is Cretaceous, coal not now being considered as representing the Carboniferous age unless accompanied by stratigraphic or paleontologic proof.

General conclusions.—From the foregoing résumé of investigations of the Texas Carboniferous the following general facts are evident:

1. It occupies two widely separated areas the relation of which is unknown.

2. The first or central area consists of coal bearing strata and is allied by geographical continuity to the coals of Indian Territory, Arkansas, Missouri, Iowa, &c.

3. The second or trans-Pecos area belongs to the great western deposit of non coal bearing, marine Carboniferous of the West.

4. Both of these areas are greatly disturbed and the Cretaceous is deposited unconformably upon them.

5. Although one distinguished authority has announced the presence of sub-Carboniferous strata in Texas, their existence has not been demonstrated,[3] and both areas probably belong to the later Carboniferous, the trans-Pecos graduating into almost Permian facies.

THE SO-CALLED PERMIAN[4] OR PERMO-CARBONIFEROUS.

The term Permian has for many years been applied, with much indefiniteness, to certain Texas strata, and it is difficult to form from

[1] Sierra Blanca.

[2] It is now known that these coals are later Cretaceous.

[3] Prof. C. A. Ashburner announced that the limestone at the base of his section (see p. 59) was sub-Carboniferous. Prof. W. F. Cummins, of Dallas, Tex., first called my attention to the fact that Mr. Ashburner was probably mistaken. From personal observation I have also good reason for doubting its existence. Not a single sub-Carboniferous fossil has been found in Texas, and the limestone of the Central Coal Measures bears great lithologic and faunal resemblances to that of the non coal bearing western strata.

[4] The word Permian has been applied for many years to various strata in the great area between the western boundary of the exposures of the Missourian or fourth coal basin of the United States and the Sierras, especially in the States of Texas and Kansas, the Territories of New Mexico and Arizona, and in Indian Territory. Prof. J. S. Newberry, at the meeting of the International Geological Congress at Berlin (1885), asserted that he believed no Permian strata to exist in the United States. Whether the existence of Permian strata here can be proved or not I cannot say, but it has been clearly demonstrated that sedimentation was going on in this country synchronously with the deposition of the Permian of Europe. That this sedimentation was different from the European in lithologic and organic characters is true.

published writings even a general idea of what was intended by those who have most frequently used it.

It has been applied by different authors[1] to at least two entirely distinct geologic horizons occupying widely separated areas. Although one of these has been described with comparatively much more distinctness than the other, there is still much danger of confounding the two. No paleontologic or stratigraphic data have ever been produced showing any relation between them.

The trans-Pecos region of Shumard.—The first locality to which the term Permian was applied was the region west of the Pecos River, near the Rio Grande, occupied by the disturbed outliers of the Rocky Mountains, known as the Guadalupe Range or Ranges.

At a meeting of the St. Louis Academy of Science, held March 8, 1858, the following report was made:[2]

Dr. Benjamin F. Shumard stated that since he had examined Major Hawn's collection from the Permian rocks of Kansas he had studied a series of fossils from the White Limestone of the Guadalupe Mountains, New Mexico, which were obtained by his brother, Dr. G. G. Shumard, while acting in the capacity of geologist of the Government expedition, under Capt. John Pope, for obtaining water by means of artesian wells along the line of the thirty-second parallel, and that he had arrived at the conclusion that these also were of Permian age. This White Limestone, he remarked, contains a number of fossils that are identical with Permian species of England and Russia, while others are near analogues of characteristic Permian forms of those countries; several are also identical with Permian species, described by Professor Swallow,[3] from Kansas. The collection contains well marked examples of *Aulosteges*, a genus that has not been recognized in formations below the Permian. The species, however, were distinct from the English and Russian forms. There are specimens which agree perfectly with the descriptions and figures of *Camarophoria Schlotheimi*, *C. Geinitziana*, and *Productus Leplayi*, as given by Verneuil and King; also a *Productus* very analogous, if not identical, with *Productus Cancrini*, and a *Terebratula*, that agrees with *T. superstes* of Verneuil in every respect except that the dorsal valve of the American fossil is not quite so gibbous. There is also in the collection *Terebratula elongata*, *Terebratula* (*Spirifera*) *pectinifera*, *Spirifer cristata*, *Acanthocladia anceps*, *Synocladia*, and fragments of a *Monotis* which approaches nearest to *M. speluncaria*. Besides these, the collection embraces new species of *Productus*, *Spirifer*, *Chonetes*, *Corals*, *Trilobites*, and a slender *Fusulina* nearly two inches in length. Scarcely any of these fossils are positively identical with forms of our western [Missouri] Coal Measures.

In subsequent papers[4] Dr. B. F. Shumard described these forms more at length, and his brother, Dr. G. G. Shumard, contributed an article[5] giving a very succinct stratigraphic description of the region.

[1] R. F. and G. G. Shumard, 1860, and E. D. Cope, 1874.

[2] Trans. Acad. Sci. St. Louis, Vol. I, pp. 112–114, 1856–1860.

[3] Ibid., p. 111.

[4] "Notice of new fossils from the Permian strata of New Mexico and Texas, collected by Dr. George G. Shumard," &c., Trans. Acad. Sci. St. Louis, Vol. I, pp. 290-297; "Notice of fossils from the Permian strata of Texas and New Mexico," &c., ibid., pp. 387–415.

[5] Observations on the geological formations of the country between the Rio Pecos and the Rio Grande, in New Mexico, near the line of the thirty-second parallel, &c., ibid., pp. 273–289.

According to the latter the white, gray, and other colored limestones forming this series have a thickness of over a thousand feet, are greatly disturbed, and have a varying dip.

The extent of these exposures is probably identical with that of the trans-Pecos Carboniferous area already described, from which the rocks are stratigraphically inseparable. These occur entirely west of the Pecos River, so far as is now known, and between the Rio Grande and the thirty-second parallel. The only points where they have been positively noted are in the section of country from 30 miles west of the mouth of Delaware Creek to the mountains in the vicinity of El Paso, Tex., approximately following the thirty-second parallel. The United States and Mexican boundary survey party noted the occurrence of similar rocks along a section parallel to the foregoing, but from one to two hundred miles to the southward. In the report of the survey, however, which was printed a year or two before Dr. B. F. Shumard's application of the term Permian, these strata were termed Carboniferous. That they are identical there is little room to doubt.

Dr. Shumard pointed out many supposed resemblances to the so-called Permian of Kansas, and, if these are real, the two areas may be in some degree related.

Concerning the western extension of this region little is definitely known, but good authorities think there is reason to believe that it is more closely related to the Permo-Carboniferous, as described in Southern Utah and along the Grand Cañon of the Colorado in Arizona, than to the Coal Measures of the Mississippi Valley and the Appalachian region.

It would of course be impossible to make any definite statements about the equivalents of trans-Pecos Permian, but it is highly probable that future investigation may demonstrate more clearly the above mentioned resemblance.

There is no reason to doubt that these rocks are a continuation of the Carboniferous sedimentation, and the remarks of James D. Dana[1] concerning the Permian rocks of Kansas are equally applicable to them, to wit: They "are continuous with the Carboniferous without interruption or unconformability, and yet are referred to the Permian because they probably belong to the Permian in geologic time or at least its earlier portion." Whether these strata are of the Carboniferous or of the Permian, they present paleontologic and stratigraphic features of a purely transitional group. If it is granted, however, that these Texas and Kansas strata are the highest Paleozoic beds in this country and if it is shown that they contain a commingling of typical Carboniferous and Permian species, the term Permo-Carboniferous would be the most appropriate one that can be applied to them.

From all the literature we have upon the subject, it is evident that at the close of the time of the deposition of these trans-Pecos, Permo-

[1] Manual of Geology, p. 369.

Carboniferous strata a great elevation had been attained and that they must have remained a portion of a continental area for some time, when subsidence ensued and the Mesozoic sediments were next deposited unconformably upon them.

The Permian of Cope and his assistants.—The second area in Texas to which the term Permian has been applied (which it should be remembered may belong to an apparently different horizon from the trans-Pecos region just described) is situated along the western boundary of the northern portion of the central area of Carboniferous exposures continuing into Texas from Indian Territory approximately along the line of the one hundredth meridian and extending southward to the thirtieth parallel.

Although this formation has frequently been alluded to in the writings of Prof. E. D. Cope, Jacob Boll, and others, nothing has been printed concerning its stratigraphy or that of the surrounding country, except the fragmentary data which I have compiled and which I present in the following pages.

From Prof. W. F. Cummins,[1] of Dallas, Tex., I have learned that the term Permian was first applied to the region by Prof. William DeRyee, who occupied the office of State chemist during the war of the rebellion. Upon what geologic evidence Professor DeRyee called the region Permian I have been unable to ascertain. The printed statement from his pen is as follows:[2]

To the Directors of the Texas Copper Mining and Manufacturing Company:

GENTLEMEN: In accordance with instructions received at Weatherford on the 12th day of June [no year is given], I hereby transmit to you the following sketch of my researches in the Wichita copper region. The limited time which I was able to devote to it and the difficulties incident to an exploration of a comparatively uninhabited district will palliate its deficiency. After traversing the *Lias* and *Carboniferous* series northward of Weatherford, I was agreeably surprised by a grand panorama of the outcropping Permian formation. This system is extensively developed in Russia between the Ural Mountains and the river Volga, in the north of England, and in Germany, where it is mined for its treasures of copper, silver, nickel, and cobalt ores. It has not heretofore been known to exist in this State, or has been mistaken for the Triassic system, which is overlying the former to the southeast. Its hills, which have been traced through Archer and Wichita Counties, resemble in shape the copper bearing and gossan crested upheavals in Ducktown, Tenn., but they are of different age and composition. They are nearly barren and, towering above the most beautiful mesquite prairies fringed by the finely timbered tributaries of Red River, are exceedingly picturesque. The members of the Wichita system, as far as open to ocular inspection by outcrop or cross-cut, making allowances for climatic differences, correspond closely with the lower strata discovered at Perm and Mansfield, but its mineral resources are evidently more promising.

[1] This gentleman is the most thoroughly informed concerning the origin and history of the application of the term Permian, having been intimately connected with Messrs. Cope, DeRyee, and Boll, who applied it so frequently.

[2] Charter and by-laws of the Texas Copper Mining and Manufacturing Company. A history of the company. Letter from the Department of the Interior, by Joseph S. Wilson, Commissioner. Prof. Wm. DeRyee's and W. F. Cummins's Geological Reports. Dallas, Texas, 1883, p. 6.

Then follows a description of the mineral products of the formation, throwing no light on its age or stratigraphy.

The foregoing is the first and only description I have been able to find in print of the Permian of the Wichita region of Texas from the pen of the man who first applied that name to its geologic formation.

In the same pamphlet are geological reports from Prof. Jacob Boll and Prof. W. F. Cummins. The former says (p. 11) of the geologic age:

> The company's land lies wholly within the transition period, especially within the lower Permian formation.

The latter says, however (pp. 8, 9):

> I had visited frequently before this trip the immediate country in which these lands are situated and had already determined the geological period to which Archer County belongs. Under an engagement with Prof. E. D. Cope, of Philadelphia, Pa., I have been for the last two years collecting fossil vertebrates of the Permian period in Archer and adjoining counties. Archer County is almost entirely within the lower Permian period. The rocks and clays of the Permian thin out to the south, where there is a fine presentation of the rocks of the upper Coal Measures. The Permian strata in Texas lie conformably above the Carboniferous measures; in fact, the Permian and Carboniferous rocks constitute a continued series, so that it is impossible to determine just where one ends and the other begins; but I am certain the lands of the company are wholly within the Permian, for I have collected fossils on these lands that are undoubtedly of that period.

Prof. Jacob Boll made the first intelligible announcement of the Permian in Northwest Texas in a brief sketch in the American Naturalist for 1880.[1] He mentioned his explorations of the previous field season, which extended over the entire length of Little Wichita River and its confluents. As the result of this six months of exploration he announced that he had discovered many new "plants and animals, consisting of petrified ferns, fishes, and reptiles." These, he asserted, all belonged to the transitional period, and especially to the lower and upper Permian.

Such is the meager testimony upon which the existence of the Permian in Texas was originally announced. I have been able to gather from a few scattering newspaper articles a better understanding of the region thus termed Permian. These articles were written by Prof. W. F. Cummins, an intimate friend and companion of Professor Boll, who accompanied him upon his journeys of investigation. The substance of the observations given in these newspaper articles is here reproduced somewhat at length, as the original publications are now inaccessible to the public.

In an article published in The Galveston Daily News, of December 1, 1884, Professor Cummins describes a geologic expedition into the country which Professor Boll was exploring at the time of his death, in 1880, in the vicinity of the Double Mountain Fork of the Brazos River, The principal object of Professor Cummins's journey was to discover the

[1] Vol. XIV, p. 684, 1880.

extent of the Permian formation in that part of the State. He had previously traced the formation from the Wichita Mountains, near Fort Sill, Indian Territory, southward to the South Fork of the Brazos River. From the fact that Professor Cummins was such an intimate friend of Professor Boll, it is inferred that they had the same ideas concerning the use of the term Permian. According to Professor Cummins it would appear that—

(1) On the west side of the Carboniferous exposure, from Fort Griffin to the Clear Fork of the Brazos, there is a series of limestone hills similar to those in Baylor and Throckmorton Counties, which he considered Permian from their stratigraphic position above the Coal Measures, although unable to determine from the poorly preserved fossils and "the character of the rocks."

(2) At the base of these hills, on the east side of California Creek, are the "red marls of the Permian."

(3) Four miles farther west, still *at the base of the limestone hills*, is the vertebrate stratum,[1] which apparently has a wide extent and seldom exceeds two feet in thickness. Fossils are abundant in this stratum, "over fifty species heretofore unknown to science having been described from these beds" by Professor Cope.

(4) Twenty miles west of the above mentioned locality is Flat Top Mountain, presenting a vertical exposure of 250 feet. These rocks belong to the Permian, but are geographically too high for the vertebrate strata, only a few poorly preserved shells having been collected.[2]

(5) Twenty-five miles north of the above mountain is Kiowa Peak, situated at the junction of Croton Creek and the Brazos River. "A trip to the mountain disclosed the fact that it is of the Permian age. The whole mountain from top to bottom was a mass of saccharoidal gypsum." Fossil vertebrates were collected in the vicinity.

(6) At Double Mountain, to the south of the above mentioned locality, "the base of the mountain is gypsum, while at least two hundred feet above are Cretaceous, the Cretaceous shells being abundant and well preserved." Between the Permian and the Cretaceous beds is an unfossiliferous bed, 60 feet thick, similar to that "which immediately overlies the Carboniferous in Young and other counties, and which has hitherto been supposed to belong to that series of beds."

From the above data, together with my own observations in the region, the Permian of Messrs. Cope, Boll, and Cummins may be described as follows:

(1) A stratum of limestone, probably a part of that surmounting the true Carboniferous hills of Shackelford County, the Permian age of which is based upon its position, the fossils being pronounced indistinct by those who have seen them. This stratum of limestone is most prob-

[1] I have been informed that the vertebrate stratum is above the gypsum beds.

[2] No study has ever been made of the invertebrate fossils of the region.

ably that described by Ashburner[1] as outcropping a few miles from Cummins's locality and belonging under the Brazos coal bed, the superincumbent strata probably being washed away by erosion. It may possibly be the White Limestone of Shumard's trans-Pecos region.

(2) The red marls so characteristic of that region of Texas and described by many travelers as occupying the gypsum beds. According to Professor Cummins, these are at the base of the Carboniferous hills above mentioned, indicating non-conformability and later deposition.

(3) A vertebrate bearing stratum, the relation to the foregoing not being known, the fossils of which have been the basis of Professor Cope's term Permian.

(4) The well known gypsum strata of Texas, which have been so often mentioned in the literature of the State. These immediately underlie the typical Texas Cretaceous, a barren stratum of only a few feet intervening.

From the foregoing it will be seen that Professor Cope's Permian, as interpreted by Professor Cummins's observations, includes all the strata in Texas west of the central Carboniferous area from the late Carboniferous to the base of the Cretaceous, inclusive. It is doubtful whether this evidence, based upon a vertebrate bearing stratum and unaccompanied by any stratigraphic detail, is sufficient to justify the application of the term Permian to such an important and unexplored series of Mesozoic rocks.

The age of this series is still in the same condition of uncertainty as before Professor DeRyee applied a name to it. The rocks may be Carboniferous, Permian, Triassic, Jurassic, or Cretaceous, or all. It is certain that they are the representatives of the sedimentation of the entire Mesozoic age previous to the well authenticated Cretaceous. A little investigation would throw much light upon the subject.

Detailed comparison will now be considered unnecessary to show that there is no similarity between the two regions in Texas to which this term Permian has been applied. The Permian of Shumard, beyond the Pecos River, whether Permian or Carboniferous, occupies a clear stratigraphic position; it is well marked by a characteristic fauna; there is no doubt as to where it belongs in the geologic succession. On the other hand, the Permian of Cope has as yet no well defined stratigraphic relations; it is involved in ambiguous uncertainty and its fossils are of a vague and indefinite character. There are no stratigraphic, lithologic, or paleontologic points common to the two, and hence they have no established relationship whatever, the latter author having applied the name apparently without knowledge of its use by the other.

[1] "Brazos coal-field, Texas," Trans. Am. Inst. Mining Eng., Vol. IX, pp. 495–506, 1880–'81.

THE JURA-TRIAS OR GYPSUM STRATA.

The few geologic observers who have traveled in Texas west of the ninety-ninth meridian, south of the North Fork of the Canadian, have all commented upon the occurrence of immense gypsum deposits in that region, but so far as I am aware no one has endeavored to offer any hypothesis as to their formation or to interpret their accompanying phenomena. Captain Marcy was the first observer to give this formation extensive notice, but he throws little light on its stratigraphic relations. He records numerous localities of occurrence, however, which are of value. He describes the strata as snow white gypsum, from fifteen to twenty feet thick, resting horizontally upon substrata of red clay and sometimes accompanied by red sandstone. Mr. Jules Marcou, who observed the same formation a few miles north of Captain Marcy's localities, in his notes conveyed the idea that these beds were white and rose colored gypsums; the beds were from one to twenty feet thick, a thin, argillaceous dolomite being found below them. Captain Pope also noted the occurrence of the same beds several hundred miles to the southwest, on Delaware Creek, where Dr. G. G. Shumard, who accompanied both him and Captain Marcy as geologist, affirmed his identification. At various other points west of the central Carboniferous exposure, between Red River and the mountains west of the Pecos, these gypsum strata have been noted and many sections given. I have observed them at several of the localities mentioned, and in Jones, Haskell, Mitchell, and other counties. At every point these gypsum strata are of the same character, consisting of white or pink deposits of saccharoidal, hydrous calcium sulphate. Sometimes they are accompanied by deposits of magnesium and other sulphates.

That these gypsum beds do exist; that they extend over a large area of country; that they do not consist of fragmentary crystals or impregnations, but are extensive, massive bedded strata, presenting a similarity of structure indicative of identical deposition, is now evident.

What bearing or relation they have to the geologic structure and history of Texas, is a most pertinent question. So far as I am aware no study has been made in this direction. Previous to 1860, when these beds were attracting the greatest attention, the formation of gypsum was little understood, and there has been no interpretation of the bearings of this region upon our American geology. The simple laws of chemical and physical precipitation of limestones, gypsums, and dolomites have but recently become aids to the stratigraphist in his studies.

The fact that the typical strata of the peculiar Cretaceous rocks of Texas have been observed by Professor Cummins and others resting immediately upon these gypsum beds is evidence that their age is pre-Cretaceous, and not the age of the Dakota group, as has recently been averred by students of the gypsum strata of Kansas. I also have reason to believe that some of the numerous "red beds" of the gypsum

region are Carboniferous, but that the age of the gypsum beds themselves is still unknown, except that they are intermediate between the Carboniferous and the Cretaceous, including what has been termed the Permian and the Jura-Trias. The intimate stratigraphy of these beds is not known, but it is probable that they are the eastern exposure of the immense deposits of the "red beds" observed throughout the Southwest, especially in New Mexico, Utah, and Arizona.

THE SO-CALLED JURASSIC ROCKS OF TEXAS.

I have already shown (page 54) that Mr. Jules Marcou referred certain of the Mesozoic rocks of Texas to the Jurassic. These rocks were along the breaks of the Llano Estacado and along the Canadian River near the boundary of New Mexico. I have also alluded to the fact that Mr. Marcou's opinions were attacked by nearly all of the leading geologists of the day,[1] none of whom visited the region, except perhaps Dr. Newberry. It was a warfare of theoretical discussion, for very little was known of the region. Mr. Marcou held to his point,[2] and has not yet conceded that these strata are Cretaceous, as his opponents unanimously maintained. It is highly probable that the fossils *Gryphæa dilatata* and *Ostrea Marshii*, upon the occurrence of which Marcou held his position, are the same species that Dr. Shumard afterwards described as *Gryphæa Pitcheri* and *Ostrea belliplicata*, and now known to occur in the well defined Cretaceous of Central Texas; but it is certain that Marcou's allegations that these fossils are Jurassic were founded upon as logical grounds as those of his opponents, who, at a distance, made them equal to the Upper Chalk. It is probable that they are the continuation of Jurassic forms into the Lower Cretaceous, which Marcou called elsewhere "Neocomian;" and from later and more definite information it is very probable that Marcou's Jurassic is basal (not Upper) Cretaceous.

Another writer, Mr. N. A. Taylor, has been outspoken in referring the Cretaceous strata of Texas to the Jurassic. He thus expresses himself:[3]

> The conformation of this great region seems to show unmistakably that it was once an inland sea, whose southern shore was probably at first along the Azoic hills below the San Saba, contracting gradually to the great backbone between [Fort] McKavett and Kickapoo Springs, whose western shore extended at least thus far, and whose northern shore may have reached the Red River. Its eastern shore probably crossed the Colorado above the mouth of the Concho, extending northward to the limit of Texas and perhaps beyond. This immense basin slopes inward from

[1] See "Criticisms on Marcou's work by American geologists," Am. Jour. Sci., 2d ser., XXVI, p. 323; 2d ser., Vol. XXVII, pp. 34, 134; 2d ser., Vol. XXVIII, pp. 153, 256, and 298; Report of U. S. Geological Survey, Vol. IX; Report of U. S. and Mexican Boundary Survey, Vol. I, Part II; Pacific Railway Reports, Vols. II and III, quarto editions.

[2] See Geology of North America, by Jules Marcou, Zurich, 1858, for gist of Mr. Marcou's defense.

[3] See The Coming Empire, or Two Thousand Miles in Texas on Horseback, by H. F. McDaniels and N. A. Taylor, pp. 314, 315, 1878.

every direction, but its deepest parts are probably along the valleys of the Concho, not far from its southern border. The altitude of Fort Concho is only one thousand nine hundred feet above the level of the sea, while that of the great ridge below Kickapoo Springs and this on which I stand must be quite a thousand feet higher. This sea in drying up left enormous deposits of gypsum, great beds and areas of salt and other alkalies, with which all the streams that flow through its ancient bed are more or less impregnated. This sea, as I believe, existed during the Jurassic age. The geologists who have written of this region, from observations at telescopic distance or no observations at all, have all assigned it to the Cretaceous; but my judgment is that there is little or no Cretaceous in it. I have seen no fossils to confirm this judgment; but this basin in general outline is totally unlike the Cretaceous as developed in other portions of Texas or elsewhere. Nor has that formation in any part of the globe, if this be Cretaceous, developed such enormous deposits of gypsum and salt. If, then, it is Cretaceous, it is anomalous and without precedent.

The region he alludes to is the central or denuded area. He says:

This portion of Texas has never been geologically examined, except in a most cursory way, and it is not always easy to distinguish Jurassic from Cretaceous fossils. The late State geologist, Professor Buckley, rode over it in an ambulance, not deviating from the El Paso stage road.

Mr. Taylor has simply taken the work of subaërial erosion to be that of a lacustrine shore line, and his Jurassic sea is the denuded area of all the formations from the Carboniferous into the Cretaceous.

Although no one could say positively that there are no strata of the Jurassic age in Texas (for the problematic gypsum bearing red beds may be of that age), it is perfectly safe to say that none have as yet been demonstrated to exist.

THE CRETACEOUS.

The Cretaceous strata of Texas form by far the most extensive and important geologic deposit of that State. Fortunately for science the earliest writings on this particular formation were very explicit. Dr. Ferdinand Roemer's Kreidebildungen von Texas and his other writings on the subject, however erroneous they may be in their deductions, are exceedingly complete and clear, so that in their perusal there can be but little doubt as to the exact opinions he entertained. He studied the Cretaceous rocks of the State from the marine Tertiary on the east to the Paleozoic rocks in the Llano County region, embracing a cross section of the entire thickness of the series. This was from Seguin to the old Spanish fort on the San Saba. He also collected all possible legendary evidence and platted upon a map his ideas of the distribution of the Cretaceous strata in Texas. His descriptions and figures of the fossils of this formation remain to this day the most accurate and perfect of any paleontologic literature of the country. The principal points he developed concerning this formation were as follows:

(1) He delineated its eastern border as extending from Presidio del Rio Grande northeastward 440 miles to the Red River, enumerating many intermediate points. This line is generally accepted to-day.

(2) He explained the peculiar lithologic characteristics — a white chalky rock, with the appearance and consistency of the German Pläner-

nerkalk, containing calcite crystals and flint nodules, a chalk marl, and a harder yellow limestone.

(3) He gave the first exposition of its organic remains and asserted their great similarity to the fauna of the Upper Cretaceous of Southern Europe.

(4) He gave the fauna of the various strata and of different localities, describing 118 species, 58 of which were new to science.

(5) He noted the escarpment line, running from the neighborhood of San Antonio northward, via New Braunfels and Austin, to an indeterminate point north of the latter city. He found the Cretaceous formation to extend in a comparatively narrow strip along the base of this escarpment, as well as far to the west along the surface of the tableland, of which it was the boundary.

He found well differentiated faunas in each of these topographic areas, and accordingly divided the formation in two great subdivisions,[1] to wit: Die Kreidebildungen am Fusse des Hochlandes (the Cretaceous formation at the foot of the highlands) and Die Kreidebildungen des Hochlandes (the Cretaceous of the highlands). He discussed the last named formation as the Cretaceous as he found it near Fredericksburg[2] and the Cretaceous eight miles west of New Braunfels.[3] Of these divisions and subdivisions he considered the Fredericksburg, or most western outcrop, the newest, and the Cretaceous at the foot of the highlands the oldest, and expressed the opinion that there could be no doubt that the latter extended under the highlands, instead of resting unconformably upon it, which recent investigations have shown to be the case.

[1] Dr. Roemer made no tabulated section of the Cretaceous of Texas, but from many statements in the text of his works it is evident that he had the following opinions of the subdivisions:

There are three general divisions of the Cretaceous in Texas, to-wit: The Cretaceous at the foot of the highlands; the Cretaceous of the highlands; the Cretaceous of the hills near Fredericksburg.

On page 17 of Kreidebildungen he says: "It is known that the hills in the country to the north of Fredericksburg, on the Pedernales River, are the latest of all the Cretaceous of the highlands of Texas." On page 18 of the same work, he says: "After these observations it cannot be longer doubted that the Fredericksburg strata belong to the youngest of the three accepted divisions of the Cretaceous period."

Concerning the relation of the Cretaceous of the highlands to that at their foot, he says (Texas, p. 379): "Before we can enter upon a discussion of the general significance of the Cretaceous strata in Texas we must endeavor to investigate how the Cretaceous, which caps the high table-lands of Texas, consisting of a series of silicious, chalky strata, are related to the earlier observed formation at the ford of the Guadalupe, near New Braunfels, and at other points along the foot of the highlands, consisting of less firm white limestone and marls. The undoubted succession of these strata cannot be seen plainly at New Braunfels.

"But, since the firmer strata of the highlands plainly occupy a much higher bluff, it is not to be doubted that here at New Braunfels the loose white chalk and chalk marls are the lowest and the firmer limestones of the highlands the highest."

[2] Comanche Peak group of Shumard.

[3] Washita Limestone of Shumard.

He intimated the westward extension to the Rocky Mountains of the Cretaceous formation, and showed that it differed materially in its organic and lithologic characters from what is now known as Meek and Hayden's section in the Northwestern Territories and that it bore slight resemblance to the Alabama section, based upon the occurrence of Hippurites.[1] He also asserted, upon the occurrence of identical organic remains, that this formation was equivalent to the Upper Chalk and displayed by both its paleontologic and its lithologic characters a resemblance to the Upper Cretaceous of Southern Europe in the countries bordering on the Mediterranean.

From the above facts, together with similar observations upon the relation of the Cretaceous of New Jersey with that of Northern Europe, he derived the following important conclusions concerning the Cretaceous of Texas:[2]

(1) The rocks of the Cretaceous period in Texas, which are generally of a chalky character, have an extensive distribution, reaching from the Red River to the Rio Grande, comprising the greatest part of the highlands (central region) and the southern border, even extending into the undulati ng region (black prairie).

(2) The rocks vary greatly in character, those of the undulating region (black prairie region) consisting of white, chalky limestones of little firmness, and those of the highlands (central region) of a great system of strata consisting in part of very firm limestone layers, with inclosures of flint nodules and intervening layers of marls.

(3) The Cretaceous formations of Texas collectively belong to the Upper Chalk (i. e., the chalk above the Gault), and so much so that they may be referred to the horizons of the white chalk (Étage Sénonien d'Orbigny) and the upper part of the chloritic chalk (Étage Turonien d'Orbigny) of Europe.

(4) The rocks of the Cretaceous formation in Texas, particularly those of the highlands (central region), upon comparison show a decided analogy with the Upper Cretaceous formations of Southern Europe, especially along the Mediterranean, which analogy is especially seen in the strong representation of the fossil family of Rudistes.

(5) The same physical differences in the natural conditions of the oceanic regions of the north of England and Northern Germany, on the one hand, and those of the Mediterranean on the other, that existed at the close of the Cretaceous age and that caused the variance in faunas and lithologic characters of the synchronous deposits in these two regions, existed at the same time and do still exist in the seas of North America. From these facts it is evident that the Cretaceous of New Jersey then bore the same relations to that of Texas[3] as did that of the north of Europe to that of the Mediterranean, and that the same northerly deflection of the isothermal lines from the eastern coast of North America to the western coast of Europe, was evident at so early a time in the earth's history as the Cretaceous.

The next observation of the Cretaceous strata of Texas was made by Dr. G. G. Shumard along the northern border of the State. He included the strata which his brother, Dr. B. F. Shumard, afterwards incorporated in his section under the name of Washita Limestone. These he traced from Fort Washita (a few miles north of the present

[1] Radiolites, as corrected in Kreidebildungen.

[2] Kreidebildungen, pp. 25, 26.

[3] The next to the latest of the European Cretaceous.

city of Denison) to east of Fort Belknap, in Young County. A comparison of his descriptions with those of Roemer shows that the Cretaceous of this northern region of Texas has many paleontologic similarities with that described by Roemer from an Indian camp on the Guadalupe, eight miles west of New Braunfels, but that their lithologic features vary greatly.

Dr. G. G. Shumard said of these strata:[1]

From this point [Fort Washita], the Cretaceous rocks were found to extend uninterruptedly until we reached the southwestern boundary of the cross timbers in Texas. From the best information I was able to procure it constitutes the prevailing formation from Fort Washita in the direction of Fort Towson for upwards of a hundred miles with an average breadth of fifty miles. It forms part of that extensive belt of Cretaceous strata that extends from Georgia to Texas, and which, from the character of its fossil fauna, is now regarded as the equivalent of the Upper Chalk of England, and with that division of the Cretaceous group to which d'Orbigny gives the name of l'Étage Sénonien. Wherever sections of the strata were to be seen, they presented the following characters: Grayish yellow sandstones, with intercalations of blue, yellow, and ash colored clays and beds of white and bluish white limestone. The limestone reposes on the clays and sandstones. At some points it attains the thickness of a hundred feet, while at others it is quite thin and sometimes even entirely wanting. It is usually soft and friable and liable to disintegrate rapidly when exposed to the action of the weather. These Cretaceous rocks are often full of fossils. At Fort Washita the layers are crowded with *Ananchytes*, *Hemiaster*, *Nucleolites*, *Ammonites*, *Ostrea*, *Pecten*, &c., descriptions and figures of which will be found in Dr. B. F. Shumard's reports on the paleontology of the expedition. We saw here some specimens of *Ammonites* several feet in diameter and weighing between four and five hundred pounds.

Mr. Jules Marcou published a more accurate description of the Fort Washita strata and fauna a year after Dr. G. G. Shumard. He showed that in that region they were greatly denuded and covered to the east by higher strata like those of Arkansas and Mississippi. He asserted that the true age of the Fort Washita strata was Neocomian.[2]

The first results of the expedition were published by Mr. Marcou, prefaced with the statement that he had as yet neither the specimens which he had collected nor a good map of the country passed through, and since the time was very short in which he could make the required report he begged that its brevity and incompleteness be excused. In this paper he announced the existence of various formations which he more or less correlated with European strata. He described the red beds of the western portion of the Indian Territory as the Trias and discussed its divisions. The most important announcement, so far as concerns the geology of the Texas region, was as follows:[3]

I have mentioned two points between Topofki Creek and Anton Chico, where the Triassic rocks are covered by more modern formations. The first of these points is

[1] Expl. Red River of La., 1852, by R. B. Marcy and Geo. B. McClellan, p. 158.

[2] This is the only recorded reference of Texas Cretaceous strata to a position below the Gault.

[3] Geology of North America, by Jules Marcou, p. 17, 1858. The wording varies from that used in the résumé printed as a part of House Doc. 129, 1854, Lieutenant Whipple's report, p. 40, and makes locations more explicit.

upon one of the tributaries of the False Washita River, Comet Creek (latitude 35° 32′ 21″, longitude 99° 14′ 40″), near our camp, No. 31, where, upon the heights, are found the remains of beds of a limestone filled with shells which I connect with the Neocomian of Europe, or, in other words, with the Lower Division of the Cretaceous rocks. This limestone is only 5 feet thick; it is of a whitish gray color, containing an immense quantity of *Ostracea*, which I consider as identical with the *Exogyra* (*Gryphæa*) *Pitcheri* Mort. * * * having the closest analogy with the *Exogyra Couloni* of the Neocomian of the environs of Neufchâtel (Switzerland). As it is the first time the Neocomian has been recognized in America, where, until now, only the Greensand and Chalk Marl or Lower Chalk have been found, I will add that these strata are much more developed at Fort Washita, where Dr. G. G. Shumard has made a collection of fossils such as *Pecten quadricostatus*, *Gryphæa Pitcheri*, *Cardium multistriatum*, *Ammonites acuto-carinatus*, *Holaster simplex*, all fossils or genera characteristic of the Neocomian of Europe. Further, at Fort Washita, the Neocomian is covered by the Greensand, containing very fine *Hemiaster*, large *Ammonites flacidicosta*, *Gryphæa sinuata* var. *Americana*, *Exogyra Texana*, &c.

This Neocomian has nearly been destroyed and carried away by denudations, for it is only found on the summits of the hills, where it appears like the ruins of ancient buildings; it occupies actually only a width of three or four miles. Probably at the time of the deposit it covered more space, but as at Fort Washita, where it has been very little denuded, it is only twenty-five or thirty miles wide. This shows it to have been but a narrow band in the immense basin of the prairies.[1]

The other reference of Mr. Marcou relating particularly to the geology of the State of Texas, although made, like the foregoing remark, upon strata continued beyond its border, was to the effect that certain other rocks on the Llano Estacado were Jurassic, as follows:

These rocks belong to the Jurassic or Oölitic epoch. Fossils are very rare in the sandstone and limestone; but the beds of blue clay which are found in the middle of this formation contain in abundance a *Gryphæa* which has the greatest analogy with the *Gryphæa dilatata* of the Oxford Clay of England and France, and which I call provisionally *Gryphæa dilatata* var. *Tucumcarii* * * * and a very large *Ostrea*, having a resemblance to the *Ostrea Marshii* * * * of the Inferior Oölite of Europe. * * * This American Jurassic presents, at least thus far, one point of considerable difference from the Jurassic of Europe and Asia, where such large quantities of *Cephalopoda* are found, such as *Ammonites* and *Belemnites*, while here the *Ammonites* are only found in the Greensand and the *Belemnites* in the Marly Chalk; and even there these fossils are never so abundant as in the corresponding strata of Europe.

In another preliminary paper, based upon specimens collected by Captain Pope's expedition, which he did not accompany, Mr. Marcou speaks as follows of the Cretaceous rocks in the vicinity of Preston, Tex., near the present site of Denison:[2]

Preston and its environs are formed of the Cretaceous rocks that extend along the Red River and the False Washita as far as the Canadian River. These rocks form also

[1] Field observations by the writer, made and published since the manuscript of this bulletin was sent to press, show that this small and hitherto unappreciated description of Mr. Marcou is really the most accurate that has ever been written on the Cretaceous formations of the Indian Territory, and that it is equally applicable to those of Texas, of which they are the continuation.

[2] In House Doc. 129, 1854. Rep. of Exploration of a Route for the Pacific Railroad near the Thirty-second Parallel of Latitude from the Red River to the Rio Grande. By Bvt. Capt. John Pope, Chap. XIII, Geol. Notes of a Survey of the country comprised between Preston, Red River, and El Paso, Rio Grande del Norte, p. 25.

the beds of the several tributaries of the Trinity River, especially of the Elm Fork of the Trinity, where your survey has found this formation very well developed, with numerous fossils. The Cretaceous consists at the base of yellowish gray limestones, filled with broken oysters, of which the most common species is the *Gryphæa Pitcheri;* then pale grayish blue clays are superposed, containing numerous fossils, such as *Exogyra Texana, Ostrea carinata, Pecten quinquecostatus, Toxaster Texanus,* &c. Upon these clays are sandy limestones, grayish white, containing large *Ammonites* and *Baculites;* the most common are *Baculites asper* and several other new species that you have collected and which I will describe in the final report. The lower part, formed of limestone with *Gryphæa Pitcheri* and blue clay with *Toxaster Texanus,* corresponds with what is called by geologists the Neocomian formation, while the upper portion, containing *Ammonites* and *Baculites,* corresponds to the formation designated as Greensand and Marly Chalk.

The next cross section of the Cretaceous strata was made along the Rio Grande, by Arthur Schott,[1] of the United States and Mexican boundary commission. This he describes as "a Cretaceous basin, which consists chiefly of strata of greensand, which extends from Las Moras to the vicinity of Reynosa, and forms a belt of 380 to 400 miles in width" (p. 34) in Texas and Mexico. In this basin he notes various lithologic characters and some slight local disturbances. In this region, "from Las Moras to the vicinity of Arroyo Sombreretillo, which is about ten miles above Laredo, lignite coal occurs frequently" (p. 35). "Prints and even remains of plants preserved in these coals indicate vegetable forms of the higher orders, as Gramineæ, and even dicotyledonous trees, such as willow and ash" (p. 35). He also notes the extension of these coals into the Santa Rosa mountainous regions of Mexico, where the strata are nearly vertical. The fossils, plants, and mollusks from these localities bear a close affinity to the coal bearing beds of the late Cretaceous of the Northwestern Territories, but their relation to that region as well as to the Cretaceous of the west of Texas is still problematic.

Dr. Benjamin F. Shumard was the next geologist to study the Cretaceous strata in the field. He had the advantage of previous observations as well as of residence in the State for a few years as State geologist (1858–1861). His writings give evidence of much labor, but, like Dr. Roemer's, they are deficient in stratigraphy and are mostly of a paleontologic character. His section of the Cretaceous strata of Texas has been accepted to the present time by most writers. I quote the section with his immediate comments upon it:[2]

The order of succession and thickness of the different members of the Cretaceous, system, so far as observed in Texas, are expressed by the following section, which is believed to be in the main correct, although it is not improbable that further researches may render some slight modifications necessary.

[1] Substance of the Sketch of the Geology of the Lower Rio Bravo del Norte, by Arthur Schott, asst. surveyor U. S. B. C., &c. Report of U. S. and Mex. Boundary Surv. Vol. I, Part II, pp. 28–48, 1851.

[2] Trans. Acad. Sci. Saint Louis, Vol. I, pp. 582–589, 1856–1860.

	Subdivisions.	Feet.	Characteristic fossils.	Eq. Nebraska section.	Eq. Alabama section.	Eq. Pyramid Mt. sec.
Upper Cretaceous or Calcareous division.	Caprina Limestone.....	60		Wanting.	Wanting.	Wanting.
	Comanche Peak group..	300 to 400	Exogyra Texana, Gryphæa Pitcheri, Janira occidentalis, Cardium multistriatum, Lima Waccensis, Ammonites Pedernalis, Natica Pedernalis, Heteraster Texanus, Holectypus planatus, Cyphosoma Texana, and Diadema Texana.			
	Austin Limestone	100 to	Gryphæa vesicularis, Exogyra costata, Radiolites Austinensis, Nautilus Dekayi, Baculites anceps.	Nos. 4 & 5 (?)	A B	
	Fish bed.....	120	Fish remains—Mosasaurus,		C	
	Indurated Blue Marl....	60	Exogyra arietina, Dentalina.	Wanting.		
	Washita Limestone.....	100 to 120	Gryphæa Pitcheri var. Tucumcarii, Ostrea subovata (O. Marshii, Marc.), O. carinata, Inoceramus problematicus, Hamites Fremonti.	No. 3.	Wanting.	E F G
	Blue Marl.....	50	Inoceramus problematicus, Ostrea, &c.	No. 2.		
	Caprotina Limestone...	55	Orbitolina Texana. Caprotina Texana. Natica acutispira.			
Lower Cretaceous.	Arenaceous group.....	80	Ostrea bellarugosa. Cyprina (?).	No. 1.	E	B C
	Fish bed.....		Fish remains.			D
	Marly Clay or Red River group.	150	Ammonites Swallovii, A. Meekianus, Ancyloceras annulatus, Scaphites vermiculus, Baculites gracilis, Gervilia gregaria, Inoceramus capulus, fossil wood.			A

I. UPPER CRETACEOUS OR CALCAREOUS DIVISION.

This division, in the eastern or settled portion of the State, attains a thickness of from 800 to 1,000 feet, but in its western extension reaches a much greater development. It presents the following subdivisions from above downwards: *Caprina Limestone, Comanche Peak group, Austin Limestone, Exogyra arietina marls, Washita Limestone, Inoceramus problematicus beds*, and *Caprotina Limestone.*

Caprina limestone.—This is the uppermost recognized member of the series, and, although of no great thickness, has a somewhat extended geographical range. It is a yellowish white limestone, sometimes of a finely granular texture and sometimes made up of rather coarse, subcrystalline grains, cemented with a chalky paste. It

generally occurs in thick, massive beds, and is capable of withstanding the action of the weather to a greater extent than most of the members of the Cretaceous system. This formation is usually found capping the highest elevations, and its presence may be nearly always recognized, even at a distance, by the peculiar flat-topped and castellated appearance it imparts to the hills [buttes]. According to Dr. Riddell, it is finely displayed along the bluffs of Brazos River, in Bosque, McLennan, and Hill Counties; also along the Leon and Bosque Rivers. The summits of the remarkable elevation known as Comanche Peak, in Johnson County, and that of Shovel Mountain, in Burnet County, consist of this rock.

The fossils are chiefly *Caprina, Cytherea,* and *Ammonites* of undetermined species.

Comanche Peak group.—The Comanche Peak group, which next succeeds in descending order, is an important member of the series, and presents a greater development, both horizontally and vertically, than either of the others. It is made up of soft yellowish and whitish chalky limestone and buff and cream colored limestones of greater or less compactness. * * *

The best exhibitions of this formation that we have seen are at Comanche Peak, Shovel Mountain, and at Mount Bonnell, near Austin.

Fossils: This group is remarkably rich in organic remains, a large portion of them, however, occurring usually as casts. The species most frequently observed are *Exogyra Texana, Gryphæa Pitcheri, Janira occidentalis, Cardium multistriatum, C. Texanum, C. Coloradoense, Pholadomya Sancti-Sabæ, Lima Wacoensis, Arcopagia Texana, Trigonia crenulata, Astarte lineolata, Cardita erminula, Corbula occidentalis, Modiola contricecostellata, Leda, Thracia, Ammonites acuticarinatus, A. Pedernalis, Scolaria Texana, Phasianella tumida, Rostellaria* (*Eulima* Sh.) *subfusiformis, Natica Pedernalis, Nerinea acus, Avellana Texana, Turritella seriatim-granulata, Cerithium Bosquense, Pleurotomaria* (undet. sp.), *Solarium* (undet. sp.), *Heteraster* (*Toxaster* Roe.) *Texanus, Holectypus planatus, Cyphosoma Texanum,* and *Diadema Texanum.*

It is quite probable that this and the preceding subdivision of our Cretaceous system are not represented in Nebraska. We have collected more than fifty species of fossils from these beds and not a single one has been found identical with any of the numerous Nebraska forms that have been described by Messrs. Meek, Hayden, Hall, the writer, and others. Neither have we seen any paleontological evidence that the beds under notice are parallel with any of the members of the New Jersey and Alabama series, though it is not improbable that a closer study of the Cretaceous rocks in Alabama will show them to exist there.

Austin Limestone.—This subdivision consists of cream colored and bluish earthy limestone, and resembles in lithological features portions of the preceding group, but contains quite a different assemblage of organic remains. Some of the beds are soft and crumble readily upon exposure, while others are moderately hard and furnish a handsome building rock, which may be cut into almost any required shape with a common handsaw. The State house and several of the public buildings at Austin are constructed of this stone. This formation occurs at Austin and near San Antonio and New Braunfels. Dr. Riddell also recognized it in McLennan and Bosque Counties and Dr. G. G. Shumard in Grayson County. The greatest thickness observed is in the vicinity of Austin, where the beds are exposed to the height of about one hundred feet.

Organic remains: The most characteristic [fossils] are *Inoceramus biformis, Gryphæa vesicularis, Exogyra costata, Ostrea anomiæformis, Arca vulgaris, Radiolites Austinensis, Nautilus DeKayi* (?), *Baculites anceps, Helicoceras, Ammonites, Cassidulus æquoreus, Hemiaster parastatus,* and scales and teeth of fishes.

At the base we have shaly layers of dark bluish gray calcareous sandstone, containing numerous fish scales, teeth of *Corax heterodon, Lamna Texana,* and remains of *Mosasaurus.*

This assemblage of fossils establishes pretty clearly that the Austin Limestone represents divisions A, B, and C of the Alabama section, as determined by Professor Win-

chell, which are regarded by Messrs. Meek and Hayden and Professor Hall as on a parallel with Nos. IV and V of the Nebraska section.

Exogyra arietina marl.—This is an indurated blue and yellow marl, with occasional bands of gray limestone and thin seams of selenite interstratified. It contains iron pyrites in the form of small spherical masses and the fossils are also frequently studded with brilliant crystals of this substance. It is well exposed towards the base of Mount Bonnell, near Austin, where it presents a thickness of about sixty feet. It may also be seen to advantage near New Braunfels, in Comal County, at various points in Bell County, and Dr. G. G. Shumard found it resting upon the limestone of Fort Washita, in Arkansas.

Fossils: *Exogyra arietina, Gryphœa Pitcheri, Janira Texana,* and a small undescribed species of *Dentalina.* On Shoal Creek, near Austin, *Exogyra arietina* occur in the greatest profusion, the surface of the ground being sometimes literally covered with them.

Washita Limestone.—This important member of our Cretaceous system is made up of a nearly white, yellow, gray, and blue limestone, some of the layers being moderately hard, while others disintegrate rapidly from exposure. This formation is exhibited at many localities in the State. Good exposures occur near Austin and in Grayson, Fannin, and Red River Counties. According to Dr. G. G. Shumard, it is finely developed at Fort Washita. * * *

Blue marl.—This member was examined in Grayson County by Dr. G. G. Shumard, who describes it as an indurated, arenaceous marl of a schistose structure, with small nodules of iron pyrites and irregular masses of lignite disseminated through it. It has not been recognized south of Grayson County.

The fossils are *Inoceramus problematicus, Ostrea,* and *Plicatula,* of undetermined species. It also abounds in fish remains, the scales and teeth of which are sometimes elegantly preserved.

This subdivision should, perhaps, be grouped with the preceding. It corresponds with No. 2 of the Nebraska section.

Caprotina Limestone.—The Caprotina Limestone, which follows in descending order, forms the base of the Upper Cretaceous and is composed of light gray and yellowish gray earthy limestone, with intercalated bands of yellow marl and sometimes flint. It is exposed at the base of the hills near Comanche Peak and is seen underlying the Washita Limestone near the Colorado, at the foot of Mount Bonnell.

Fossils: The lower portion abounds in *Caprotina Texana* and the upper portion contains *Orbitolina Texana, Panopœa Newberryi, Cardium Brazoense, Arca Proutana, Cytherea, Cyprina, Natica acutispira, Phasianella perovata,* and *Cerithium,* and *Nerinea,* of undetermined species.

II. LOWER CRETACEOUS.

For a knowledge of this division of our Cretaceous system I am indebted to Dr. G. G. Shumard, who has had excellent opportunities for examining it. He describes it as being composed of sandstones and gypseous and marly clays, the latter containing numerous septaria, filled with fossils. It is separable into two groups, namely, Arenaceous and Marly Clay or Red River group.

Arenaceous group.[1]—This member consists of light yellow and blue sandstone and beds of sandy clay, with crystals of selenite and some lignite. Its characters may be understood from the following section, taken by Dr. G. G. Shumard on Post Oak Creek, in Grayson County:

No. 1.	Soft, fine grained, yellow sandstone	10 feet.
2.	Hard, fine grained, blue sandstone, becoming yellow upon exposure, and sometimes passing into gritstone and fine conglomerate	5 feet.
3.	Yellow sandstone, same as No. 1	10 feet.
4.	Indurated, blue, slaty clay, with crystals of selenite	20 feet.
5.	Thinly laminated layers, same as No. 2	3 feet.

[1] Dakota Sandstone. See Trans. Acad. Sci. St. Louis, Vol. II, p. 140, quoted, p. 176.

Fossils: The upper part is characterized by *Ostrea bellarugosa* [*O. belliplicata?*], *Ostrea congesta, Lucina, Plicatula,* a small species of *Cyprina (?),* fossil wood, and occasionally obscure impressions of plants. The *Ostrea* occurs in distinct bands and is extremely abundant. The lower beds have yielded an undescribed species of *Lingula* and abound in fish remains which Dr. Leidy refers to the following species: *Ptychodus mammilaris, Lamna compressa, L. Texana, Galeocerdo pristodontus,* and *Carcharodon.* * * *

With regard to the Nebraska equivalent of our Arenaceous group, I think there can scarcely be a doubt that it represents No. 1 (perhaps the upper part) of the section of Messrs. Hall, Meek, and Hayden. * * *

Marly Clay or Red River group.—This member immediately underlies the fish bed of the Arenaceous group and is described by Dr. G. G. Shumard as "a blue, marly clay occasionally variegated with red and brown, and with thin bands of sandstone interstratified. The clay contains crystals of selenite, flattened nodules of compact brown and blue limestone, and septaria of compact, blue limestone, reticulated with brown, yellow, and purple spar. The nodules occur in the upper, and the septaria towards the base of the formation. The best exposures of the group are in Grayson, on Post Oak, Choctaw, and Big Mineral Creeks, where sections of from fifty to sixty feet have been measured. It occurs also on Red River, Fannin and Lamar Counties. The estimated thickness of the group in this part of the State is about one hundred and fifty feet, but we have not seen the base of the formation."

Fossils are exceedingly abundant in the septaria and nodules, and so far as I have been able to learn they belong to hitherto undescribed species. From the collections of Dr. G. G. Shumard I have been able to characterize the following: *Ammonites Swallovii, A. inæquiplicatus, A. Meekianus, A. Graysonensis, Ancyloceras annulatus, Scaphites vermiculus, Baculites gracilis, Cytherea Lamarensis, Tapes Hilgardi, Gervilia gregaria, Nucula Haydeni, Panopæa subparallela, Corbula Graysonensis, C. Tuomeyi, Inoceramus capulus,* and *Inoceramus,* n. sp. Fossil wood is also quite common at several of the localities visited.

The section contains what have been called grave discrepancies by another writer,[1] and from my residence in the State I think the criticism well founded. Why these errors appear in Shumard's section is easily explained. It is a composite one, made up at the city of Austin from the observations of three geologists working in widely separated portions of the State, and influenced by his predilection towards Roemer's opinions. His Comanche Peak series is evidently the same as Roemer's Fredericksburg subdivision, his Austin Limestone is Roemer's Kreidebildungen am Fusse des Hochlandes, and his Washita Limestone is the same as described by his brother and Mr. Jules Marcou. The lower part of his section is based upon the observations of his brother along Red River, where the lithologic and paleontologic variations are different from those of synchronous formations of other parts of the State. Dr. Riddell, assistant geologist, studied the formations in Bosque County, while Dr. B. F. Shumard himself studied them at Austin. He arranged, as he thought the data warranted, these observations of his brother on Red River, those of Dr. Riddell's in Central Texas, and his own and Dr. Roemer's near Austin to make up

[1] See "Notes on the Cretaceous and Carboniferous rocks of Texas, by Jules Marcou," Proc. Bost. Soc. Nat. Hist., Vol. VIII, pp. 86–97, 1861–1862.

the published section. From this section, by careful comparison of Roemer's work, it will be seen that he had the same fundamental opinion, to wit, that the Cretaceous of the lower land east of Austin extended under that of the table lands to the west, and that the tops of the hills (buttes) farther inland was the newest Cretaceous of the State.

Upon the publication of this section, Mr. Jules Marcou wrote a criticism of the same,[1] in which he pointed out many discrepancies in sequence of the groups and rearranged Dr. Shumard's section upon his own data, as follows:

Upper Cretaceous or Senonian.	Austin Limestone. Fish bed in sandstone (*Lamna Texana*). Blue Marl, with *Inoceramus problematicus*.	Arenaceous group with *Ostrea congesta*. Fish bed, *Lamna Texana* &c.
Middle Cretaceous or Greensand and Turonian.	Marly Clay or Red River group. Caprina Limestone. Comanche Peak group (superior part with *Exogyra Texana*). *Exogyra aristina* marl.	
Lower Cretaceous or Aptian and Neocomian.	Washita Limestone (comprising the inferior part of the Comanche Peak group, with *Gryphæa Pitcheri*). Caprotina Limestone.	
	Trias or Carboniferous.	

From my own observations in the State I am inclined to believe, notwithstanding the disagreement with older geologists, that Mr. Marcou's deduction is more in accordance with the actual relations of the strata than any other published and especially than those of Roemer and Shumard.

In the following years (1861, 1862) Dr. B. F. Shumard announced the occurrence of two more groups of the Cretaceous in Texas. The first of these was the Ripley group of Mississippi, which he announced before the Academy of Science of Saint Louis to have been found in Navarro County, Tex. The other was the Dakota sandstone, which he reported from Grayson County. He studied the first named group and identified over twenty species common to the Tippah County (Mississippi) beds and the Navarro County (Texas) beds. Concerning the alleged occurrence of the Dakota sandstone in Grayson County, he said that he based his opinion upon the occurrence of dicotyledonous leaves in the ferruginous sandy strata there,[2] of which he would speak further

[1] Proc. Bost. Soc. Nat. Hist., Vol. VIII, pp. 86–97, 1861.

[2] You will, perhaps, remember the statement in my paper on the Cretaceous strata of Texas (p. 589 of Transactions) that, although we had not succeeded in finding dicotyledonous leaves in the lower Cretaceous marls and sandstones of Texas, as has

at a future day, an expectation not fulfilled. These leaves, however, are now thought to be from the lower cross timbers strata, which are on a direct line of geographic continuity with the alleged Dakota of Kansas.

Dr. Shumard died without incorporating these later additions into his geologic sections. If he had done this it would have been necessary to revise the relative position of the strata entirely. He deserves credit, however, for some points which are not dwelt upon in his writings; one of these is the correlation of the groups of other States with those of Texas. He was the first to prove conclusively that the Cretaceous of the other Gulf States[1] was represented in Texas and also to intimate the occurrence there of the Dakota sandstone.[2]

Dr. R. H. Loughridge, in his sketch of the geology of the State,[3] shows clearly the occurrence of the Gulf States formation along the eastern portion of the Cretaceous areas of Texas, and traces it to the line of the Red River, north of which it had been identified and studied by D. D. Owen, in Arkansas, many years before.

From the observations of all these geologists the following is at present known concerning the Texas Cretaceous:

(1) It has been studied hastily and independently along three widely separated, parallel cross sections, to wit, by Dr. G. G. Shumard and by Jules Marcou along the northern borders, by Dr. Ferdinand Roemer and by Dr. Benjamin F. Shumard in the central (Austin and New Braunfels) region, and by Arthur Schott along the Rio Grande. The section as studied by the last mentioned, being the continuation of Mexican geologic features into Texas, has but slight resemblance to the Cretaceous of the rest of the State, so far as it has been studied.

Concerning the rest of the State two diverse opinions have been presented, especially concerning the order of sequence and the correlation of the Cretaceous strata of most of the State of Texas, one of which is based upon observations of a cross section south of Austin across the

been done by Meek and Hayden in Nebraska and Kansas and Newberry in New Mexico, they would probably be found in this position. I have now the pleasure of informing you that further explorations in Lamar County, near the Red River, have resulted in the discovery, by Dr. G. G. Shumard, of numerous impressions of leaves in alternations of yellowish sandstones and bluish shales which are believed to occupy a position below the Marly Clay or Red River group of my section, and which we regard as being on a parallel with the lower beds of No. 1 of the Nebraska section. The collection made by Dr. G. G. Shumard contains several species of monocotyledonous leaves which appear to belong to the genera Salix, Ilex, Laurus, &c. I am unable to determine positively the generic affinities of these leaves, for want of proper works of reference, but shall submit the collection to a competent fossil botanist, and think they will be found analogous to those discovered by Meek and Hayden at the base of their Nebraska section. (Trans. Acad. Sci. St. Louis, Vol. II, p. 140. Read Nov. 5, 1860.)

[1] Trans. Acad. Sci. Saint Louis, Vol. II, p. 152, 1861, and Proc. Bost. Soc. Nat. Hist., Vol. VIII, pp. 188–205, 1861.

[2] Trans. Acad. Sci. St. Louis, Vol. II, pp. 140, 141.

[3] Tenth Census: Report on Cotton Production in the United States, Vol. V, Part I, *pp. 653–829. Report* on the Cotton Production in the State of Texas, 1884.

eastern escarpment of the central region while the other is based upon a cross section along the northern border of the State. The first of these opinions, formulated by Roemer and reiterated by Dr. B. F. Shumard, makes the eastern division of the Cretaceous (the Gulf series) the oldest and the northwestern the newest, and correlates the whole with European strata later than the Gault.

The other opinion, and the one hitherto least accepted, partially on account of its manner of presentation, is that the Cretaceous strata are exposed in descending series in going from east to west, and that the limestone group is of the Neocomian age instead of Senonian, or White Chalk, as asserted of these strata farther south by Roemer and the Shumards. This is the opinion of Jules Marcou, as briefly expressed in 1858, and I think it the most plausible.

Concerning the extent of this formation in Texas much has been given. Roemer platted the eastern boundary from Clarksville, Red River, to near Laredo, on the Rio Grande. This boundary has not been changed by more recent observations, but rather confirmed.[1] The Cretaceous has been reported west of this line far beyond the western boundary of the State, being interrupted only where it has been denuded from above the Paleozoic and early Mesozoic areas.

It is also very well demonstrated that the eastern portion of this Cretaceous is a continuation of the Rotten Limestone and probably other subdivisions of the Cretaceous from the other Gulf States; that in the central portion of the State there is a lower division from which the overlying strata have been eroded, which is unique and probably older than the marine Cretaceous of the United States and different from them; and that along the lower Rio Grande there is an elongated area of coal bearing strata, which Mr. Schott denominates late Cretaceous and which has marked paleontologic affinities with the Upper Cretaceous of the Northwestern States and Territories.[2]

[1] Dr. R. H. Loughridge givesthe eastern boundary of the Cretaceous a great western deflection from San Antonio to Eagle Pass. This is a mistake, founded primarily on an error of Conrad's, whereby he gave the wrong localities to certain Tertiary fossils, now known to be from the vicinity of Laredo. See p. 85; also, Tenth Census, Vol. V, Part I, Report on Cotton Production in Texas.

[2] There is reason to believe that these late Cretaceous coals underlie much of the Rio Grande, trans-Pecos, and Upper Canadian regions of the State. They have been recently reported all along the Rio Grande between Laredo and El Paso, at White Oaks, New Mexico, and at other places. They are probably the same coals of which Dr. Edward Hitchcock speaks in his Report accompanying Exploration of the Red River of Louisiana in the year 1852, by Randolph B. Marcy, captain Fifth Infantry. 1854, 33d Congress, 1st session, House of Reps. Ex. Doc., Appendix D, p. 144. He says: "I ought to have mentioned that among the specimens in my hands is one of lignite, collected July 3 near the sources of Red River, not far from the Llano Estacado and within the limits of the gypsum deposit to be described. It is an exceedingly compact coal and burns without flame, emitting a pungent but not bituminous odor. It is doubtless Tertiary or Cretaceous, but I think, if in large masses, it might easily be mistaken for anthracite."

THE SO-CALLED LARAMIE.

No observations of the true brackish water Laramie formation, which marks the transition from Cretaceous to Tertiary in the West, have been recorded from Texas. The term has been misapplied[1] to the lignitic strata at the base of the Gulf Tertiary in Eastern Texas, but this is not the true Laramie of the West. That the same species of vegetation grew along the coast of the marine waters of the old Gulf of Mexico as well as of the great Laramie basin in the interior of the continent is more than probable, but the term Laramie is a local group name and is not applicable to the synchronous subdivisions of the marine Cretaceo-Tertiaries.[2]

That the true Laramie may occur in the trans-Pecos region is not improbable, but it has not as yet been so recorded.

THE TERTIARY.

But one area of Tertiary formations has been positively identified in Texas, and that is the continuation of the Gulf States (marine) Tertiaries from Louisiana and Arkansas into its northeastern borders. Prof. Angelo Heilprin[3] has said nearly all that can be said of them. He remarks:

> The Tertiary formations of this State are yet too imperfectly known to admit either of an absolute localization of the various boundary lines or of an accurate subdivision into the minor geological groups. It may be safely assumed, however, from the geological conformation of the neighboring States, that all, or nearly all, of the divisions ranging from the Eolignitic to the Grand Gulf, inclusive, are represented, and that the positions occupied by these follow each other in regular succession, beginning with the oldest, from the interior coastward, with a general dip to the southeast or east. The geological notes on this region by Schott, Hall, and Conrad, and of Shumard and Buckley are exceedingly meager and unsatisfactory, and give us barely more than a general idea as to where the Tertiary formation exists.
>
> According to Dr. Loughridge, who, more than any other geologist, has closely investigated the outcrops of the different formations occurring throughout the State, the Cretaceo-Tertiary boundary line starts on the northeast from the Red River at a point a few miles above Texarkana, on the Arkansas frontier, and, taking a general southwestern direction, passing at or near Clarksville, Red River County; Corsicana, Navarro County; Marlin, Falls County; Cameron, Milam County; Elgin, Bastrop County; Seguin, Guadalupe County; and the northwest corner of Atascosa, crosses the Rio Grande at about the mouth of Las Moras Creek.

Professor Heilprin also says (p. 38) that the "westerly deflection, indicated as beginning a few miles south of San Antonio and extending to the Rio Grande, can scarcely be said to be definitely proved as yet, although Loughridge affirms that 'the glauconitic sandstones mentioned

[1] On the Zoölogical Position of Texas, by Edward D. Cope. Bull. U. S. Nat. Mus., No. 17, p. 5, Washington, 1880.

[2] In justice to Professor Cope it is but fair to state that this is more of a difference of opinion as to nomenclature than as to geologic time.

[3] Contributions to the Tertiary Geology and Paleontology of the United States, by *Angelo Heilprin, pp. 37 et seq.*, 1884.

by Mr. Schott as occurring along the river [Rio Grande] from the Cretaceous rocks at the mouth of Las Moras Creek, north of Eagle Pass, southward to Roma, near Rio Grande City, are doubtless of Tertiary age.' Further evidence is needed on this point, however, although some confirmation of the supposition is lent by the discovery of Tertiary fossils (*Cardita planicosta* among others) in a locality (Arroyo las Minas), situated between El Paso and Leon."[1]

I have carefully studied the literature and the facts concerning this supposed western deflection of the Tertiary strata as reported by Loughridge in Texas and accepted by McGee in his map of the United States accompanying the Fifth Annual Report of the U. S. Geological Survey. The first recorded boundary between the Cretaceous and the marine Tertiary was that made by Roemer in his writings before mentioned. It was practically the same as that of Loughridge, without this western deflection, and made the Cretaceous end on the Rio Grande near Presidio del Rio Grande, a short distance above Laredo. The work of the United States and Mexican boundary survey is misinterpreted through a small error of Conrad, who in his published description states that the *Cardita planicosta* comes from Arroyo las Minas, a small creek in what is now Zavalla County. The label pasted upon the original type specimen of this fossil,[2] in Mr. Arthur Schott's handwriting, as identified by his son, Albert L. Schott, reads as follows: "Cretaceous ridges next to the Arroyo Sufre, in the vicinity of Mier, Mexico. Schott, October, 1853." Hence it is presumable that this fossil is valueless for determining the alleged western deflection. Dr. Loughridge's other data for making this change in the accepted map is his belief that certain strata described by Schott as Cretaceous are Tertiary. I have described these strata on page 76, and from personal observation, as well as from much paleontologic material in the U. S. National Museum, I know them to be Cretaceous. Among the fossils described from them by Conrad, and with locality labels pasted upon them by Schott, are the following from Jacun, three miles east of Laredo:[3] *Ammonites pleurisepta*, *Exogyra costata*, *Inoceramus cripsii* Mantell, *I. Texanus* Conrad, *Ostrea crenulimargo* Roemer, *Dosina*, *Turritella*, *Natica*, and *Ammonites pleurisepta* Con.[4] These fossils are positively known to belong to the Cretaceous, and the locality where they occur is one hundred and fifty miles east of the boundary of that formation as deflected by Dr. Loughridge.

The *Exogyra costata* and *Inoceramus cripsii* are characteristic fossils of the Upper Cretaceous of all the Gulf States, and the *Ammonites pleu-*

[1] Report U. S. and Mex. Boundary Survey, Vol. I, Part II, pp. 141 and 161.

[2] Now in collection of the U. S. National Museum.

[3] Report on U. S. and Mex. Boundary Survey, Vol. I, Part II, p. 143.

[4] Ibid., p. 159. This species is described under the name of *Ammonites pleurisepta*, but figured (Plate XV) as *A. pedernalis*.

risepta of Conrad is a typical fossil of the peculiar formation which Mr. Schott described and is now known to be very late Cretaceous. Even were it not for the original label pasted on the *Cardita planicosta*, alleged to be from Arroyo las Minas, a glance at the fauna among which it is placed by Mr. Conrad[1] would be sufficient to show that it is a stray specimen, for the rest are all typical Cretaceous forms. Instead of this western deflection of the Tertiary in Texas I am of the opinion, from the evidence we have, that it is many miles to the east of Laredo.

This eastern or Gulf Tertiary has been recognized as such by several authors under many names. Roemer noted the presence of beds similar to those at Fort Claiborne, Ala., and after a revision of all the printed evidence it is to be doubted whether much more is known about the Tertiary in Texas than is implied in his remark and noted on his map, to wit:

> It is hardly to be believed that this Tertiary formation of Texas is to be found exclusively in the country of the Brazos [where he observed it]. It occupies a very similar zone to the Tertiary of Alabama, Mississippi, and other States, and like it, at most places is at the foot of the Cretaceous to the west and covered to the east by diluvial strata. (Texas, p. 372.)

Several other areas of the Tertiary have been reported besides this continuation of the Gulf group. The principal of these are the two anomalous forest regions known as the cross timbers. Dr. S. B. Buckley calls these Tertiary, Miocene, Eocene, &c. in his reports, but his evidence, as stated, is not such as to warrant his deductions.

The stratigraphy of the Tertiary in Texas has been neglected entirely, and we have nothing concerning its exact relation to the Cretaceous below or to the later formations. Neither is there any information concerning the stratigraphy of the group itself. In fact, the development of these strata is still to be made. All that can possibly be said of it at present is that it possesses certain broad resemblances to the Tertiary of the other Gulf States and that it consists of unstudied strata, lignitic at the base and ferruginous higher up. It rests upon the Cretaceous strata, but no evidence has been taken to ascertain whether it is simply a continuation of the sedimentation of that period or whether there is a non-conformity between them. Neither is there any evidence concerning its relation to the post-Tertiary strata.

QUATERNARY AND OTHER POST-TERTIARY STRATA.

Very little is known concerning the surface geology of Texas or of the later formations, but it is apparent that the great deposits of the coastal region result from the erosion of the interior surface. Dr. Ferdinand Roemer wrote the most of what we now know of these formations. He divides the coastal region of Texas into the alluvial and the diluvial region and describes the character of the drift and depositions of each.

[1] *Ostrea carinata* Lam., *O. anomiæformis* Roemer, *Neithia occidentalis* Con. Report U. S. and Mex. Bound. Survey, Vol. I, Part II, p. 143.

He showed that there was considerable very recently made land extending for a varying distance inland from the coast, and that it was so recent in deposition that it contained at Houston, 50 miles inland, the fossil shells whose living representatives are found in the bay of Galveston. He also describes with much clearness certain of the older drifts, but his descriptions are purely local. Dr. R. H. Loughridge notes the occurrence of Quaternary stratified drift as composing the arenaceous, cross timber region of Central Texas, and other writers have noted the drift of the lower Brazos, Red, and Colorado Rivers. The various papers of the United States and Mexican boundary survey reports describe several peculiar drift formations of the Rio Grande along its course from its mouth to El Paso. The presence of a fine, decomposing mass of pebbles over the gypsum beds has also been mentioned by writers on that region. In fact, the literature is full of fragmentary reference to local superficial formations, which we are left to presume to be of any age we please, but absolutely nothing has been done towards classifying these phenomena. It is well known that the "red rises" of the great rivers of the Texas region have been carrying down their loads of sediment, taken from the receding escarpment of the plains among which they rise, and depositing them in the lagoons along the coast. The richest sugar lands of Louisiana and Texas have been built up in this manner, in almost recent times, and the vastness of the process is grand and impressive beyond expression. No other theme is so promising to the future geologist in the region under discussion as the subject of the laws of distribution and the age of the post-Cretaceous formations of Texas

GEOLOGICAL DEDUCTIONS.

From these fragmentary writings we can only make the following general deductions concerning the geology:

The Cambrian and Pre-Cambrian strata probably underlie the State and extend as far west as the Grand Cañon of the Colorado. Upon these are deposited Lower Silurian rocks, with occasional outcroppings in the limited central and trans-Pecos areas. The Devonian strata are absent. The Carboniferous strata present two phases and are in two widely separated areas, the first being a continuation of the Missouri coal fields through Indian Territory into Northern Texas and the other being a continuation of the non coal bearing strata from the great West. Little is known of the intimate relations of the strata between the well defined Carboniferous and the Cretaceous, but there are many ideas concerning them: (1) The older Mesozoic, consisting of an extensive deposit west of the ninety-ninth meridian, extending all the way, perhaps, from the typical Coal Measures of the Carboniferous to the well defined fossiliferous lower Cretaceous. This group comprises the gypsum bearing strata, and has been called in our literature Permian, Permo-Carboniferous, Triassic, Jura-Trias, and the Dakota group of

the Cretaceous. The minute stratigraphy of these strata has never been studied and their exact age is still an unsolved problem. (2) The fossiliferous Lower Cretaceous, being easily distinguished everywhere by its unique lithologic and paleontologic characters. It overlies nearly all of the older formations, the latter being exposed usually by the erosion of its strata. Concerning the character and extent of this formation very little is known, and it is only determinable by the peculiar individuality of its fauna and the interpretation of Mr. Jules Marcou's description of a small local outcrop. It can only be said that this formation does exist, that it is older than all writers except Mr. Marcou have made it, and that its extent seems to be confined to the portion of Texas west of the black prairie region and indeterminately southward into Mexico. The higher divisions of the Cretaceous immediately overlie this. These have been traced directly from the older Gulf States, and, like the succeeding Tertiaries, seem to represent the earlier stages of the contracting shores of the present Gulf of Mexico. The Tertiaries are generally conceded to be merely a continuation of the Tertiaries of the older Gulf States, with local variations. The coast of the Gulf of Mexico of to-day is a continuation of the results of the same forces in operation since Middle or early Cretaceous time, so far as can be ascertained by interpretation of all the evidence.

GENERAL CONCLUSIONS.

Only a word is necessary to express the net results of all the observations described in the previous pages. The following facts are obvious:

(1) There is no accurate knowledge of the essential topographic features of Texas upon which geologic work can be based.

(2) The geologic work has been fragmentary, unconnected, uncorrelated, and unsystematic throughout. It has been mostly descriptive paleontology instead of stratigraphic work.

(3) There has been very little accurate stratigraphic work recorded.

(4) Most of the literature deals with broad generalities rather than with specific description.

It is evident that very little of the work deserves to be classified above preliminary reconnaissance and that the need of the future is apparent: the careful study of typical sections by combined stratigraphic and paleontologic data, the tracing of the extent and variation of these features, and, first of all, a correct and reliable topographic survey of the entire State. There is not on record a clear and intelligible section of a single local area.

In the preceding pages I have tried to prepare the way for honest students to take up the work without long years of weary research in endeavoring to find out what has been done in this great region. No portion of our country is more pregnant with unstudied features of

geologic interest. Important relations in the history of the continent have been traced to its borders on every side and stopped there by a want of minute knowledge of its formations. To the student who will undertake the solution of a single one of the questions involved the reward will be results of incalculable value. Among these problems are the history of the river systems, the elevation of the land features from the sea, the effects and the results of subaërial erosion, the intimate features of the stratigraphy, the tracing of ancient interior continental shore lines, the history of the recession of the escarpment lines (especially that of the Llano Estacado), the building up of the coast by the sedimentation resulting from this erosion, the accurate enumeration and distribution of typical faunas, and the stratigraphic position of its fossils, and, chief of all, the deduction from these scientific determinations of those economic results appertaining to agriculture, industry, and commerce without which the true possibilities and impossibilities of the great region will forever remain unknown and its development depend upon blind and costly experiment.

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UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

NATURE AND ORIGIN

OF

DEPOSITS OF PHOSPHATE OF LIME

BY

R. A. F. PENROSE, Jr.

WITH AN

INTRODUCTION BY N. S. SHALER

WASHINGTON
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INTRODUCTION.

By N. S. SHALER.

The circumstances which have led to the preparation of the subjoined report on mineral phosphates are as follows, viz: In 1870 the present writer was employed by the Superintendent of the Coast Survey, the late Benjamin Peirce, to examine the phosphate beds of South Carolina with a view to determining the limits of that field; it was also deemed desirable to ascertain, if possible, the conditions which led to the formation of the deposits.

It was at that time the intention of Professor Peirce to have the geology of the belt of country within the limits of the Coast Survey maps carefully determined, so that they might be shaped in a way that would better serve the commercial interests of the country and also have a greater scientific value. After a time it appeared that there were legal difficulties in the way of publishing these studies in the reports of the Coast Survey and this work was suspended. It was the hope of Professor Peirce to secure a modification of the law, but before this was accomplished he retired from the post of Superintendent and his successor deemed it best to abandon the project. During the two years in which I was engaged in this work on the geology of the coast line I became very much interested in the problems connected with the origin and distribution of phosphatic deposits. From 1873 to 1880, while employed as State geologist of Kentucky, I had a chance to see a good deal of the somewhat phosphatic limestones of the Cambro-Silurian sections, a set of beds which, by their decay, have given great fertility to the soils that lie upon them. The researches of Dr. Robert Peter, the chemist of that survey, made it plain that the phosphatic contents of the soils are among the first materials to be exhausted by the careless tillage which characterizes our American agriculture, and that they are the most costly to restore to the soil.

Extending the general inquiry to the grain-producing districts which lie to the north and west of Kentucky, it became evident that all those States, which are now the granary of this country and the chief source of supply for European markets as well, are rapidly exhausting their soils and will soon be in grave need of phosphatic manures. The im-

portance of such manures has so far been well recognized only by the cotton growers of this country, yet it is evident that in a short time this class of fertilizers will be equally in demand for all forms of grain crops.

These considerations have led me to the conclusion that the geological history of phosphatic deposits should receive more deliberate attention than has yet been given to it.

When I began my work in the U. S. Geological Survey, I asked permission of the Director to continue my studies on phosphatic deposits. There was at the time no money available for these studies; it was therefore necessary that they should be carried on without other expense to the Survey than that involved in the small share of my time which could be given to the supervision of the work. It was my good fortune, however, to find in one of my students of geology, Dr. R. A. F. Penrose, jr., a person who was willing at his own cost to undertake a preliminary study of the whole field as far as our knowledge extends and thus to prepare the problems concerning American phosphate deposits for detailed inquiry. This work he has pursued with great intelligence and energy during the two years in which he has been engaged in it. In this task he has examined all the known phosphate deposits of the United States and Canada and has made a careful inquiry into the literature of the subject, as is shown by the extended bibliography which is appended to this report.

The object of this work being to make a necessary preparation for the further study of the American phosphatic deposits, Dr. Penrose's studies were not designed to be encyclopedic in their scope, but rather to afford a synopsis of what is known of the deposits in this and other countries. So little is yet generally known of the several conditions under which these deposits may occur that it would be very blind work to search for them in this country without a careful endeavor to bring together the experience which has been gained in other countries. It will be evident to the reader of Dr. Penrose's report that the workable deposits of phosphates are found in a greater variety of circumstances than those which contain most mineral substances that have an economic value. It is not likely that we have as yet exhausted the inquiry into the modes of occurrence of this substance; but this synopsis of the experience in this and other countries, which is much more extensive than any other which has been published, will, I believe, serve as a guide to the further search for sources of supplies of phosphatic manures. It will also be evident to the reader that the conditions of occurrence of these deposits in Europe make it plain that the search for them in this country may advantageously be directed to many districts in which they have not as yet been found.

So far the vein deposits of apatite, such as those which are so abundant north of the St. Lawrence, have not been found in workable quantities *within the limits* of the United States, though the general geo-

logical conditions of the Laurentian area exist in the Adirondack district and in the southern parts of the Appalachian system as well as in several districts of the Rocky Mountains. It would be remarkable if extensive deposits of this nature, so common in Canada and in the equivalent rocks of northern and southern Europe, should not be found at many points in our American Archæan formations. It is on this account that so much space in this report is given to the description and illustration of the Canadian apatite deposits. So, too, we may hope to find in the ancient rocks of this country deposits analogous to the great Logrosan and Cáceres veins in the province of Estremadura, Spain.

The Cretaceous deposits of Belgium (which at the present time are, next after the phosphate beds of South Carolina, the most productive in the world) present a type of beds not yet found in paying quantities in the United States, though deposits of the same age, formed under about the same conditions, abound in this country. It is not to be expected that phosphatic deposits will exactly repeat themselves in strata of the same age in widely separated regions; yet it is clear from the summary account of the geological distribution of these phosphates in Europe and North America that in the case of these, as well as in that of other substances of value in the arts, there are certain guiding principles which we may base on the stratigraphy of the deposits to aid our search. The known workable deposits of a phosphatic nature are limited to certain portions of the geological section. Beginning at the surface of the deposits now forming, these zones are, in descending order, as follows:

(1) Superficial deposits, including (*a*) those formed in the manner of guanos; (*b*) the deposits formed in the bottoms of fresh-water swamps, sometimes in connection with deposits of bog iron ore (hematite); and (*c*) deposits which are the result of the long-continued decay of rocks containing a small portion of lime phosphate intermingled with lime carbonate, as, for instance, the deposits of North Carolina. This superficial group of deposits has no other common feature save that they are on the surface and are due to causes now or recently in action.

(2) Deposits of the Tertiary and Upper Cretaceous. These deposits are generally the result of reactions which took place on ancient land surfaces, the phosphatic matter being such as formed in swamp beds or in ablation deposits like those of the Carolinas or of eastern England. Below the level of the Cretaceous no important deposits of phosphate have been found in the vast section of rocks which lies between that era and the Devonian horizons.

(3) In the horizons below the level of the Upper Silurian bedded rock phosphates and apatite deposits occur. These infra-Devonian bedded rock phosphates seem to have derived their phosphatic matter from the animals, brachiopods and small crustaceans, which separated that substance from the sea insects or other food which the old oceans afforded.

These phosphate-bearing invertebrates appear to have been particularly abundant in the early Paleozoic seas.

(4) Below the level of the Silurian the phosphatic deposits which have been worked probably belong altogether to the class of apatites or crystallized lime phosphates, and are probably all new deposits. They evidently occur through a large part of the Laurentian section, though, so far, the known deposits of economic importance are possibly limited to one portion of that vast series of rocks.

The apparent absence of phosphatic deposits of economic importance in the section between the Devonian and the Cretaceous is remarkable. It is possible that it may be due to our lack of knowledge as to the chemical character of the deposits in those parts of the earth's crust. It is more likely, however, that such deposits do not there exist, owing to the fact that the invertebrate species of animals which secrete phosphatic matter in their skeletons became relatively less abundant in the middle portion of the geological section; while the vertebrate species, the birds which accumulate guanos and the fishes which afford an abundance of bones and teeth to littoral deposits, as well as the mammalia whose skeletons occasionally form a considerable element in the later deposits, did not begin to contribute phosphatic matter to the rocks until comparatively modern times.

The absence of phosphatic deposits in the Upper Paleozoic and Lower Mesozoic strata is well shown by the fact that, while in the Carboniferous and the Triassic beds there are abundant land surfaces which have been carefully explored, no phosphatic deposits of economic importance have been found in them, while on the relatively very limited areas of the Tertiary and Cretaceous formations where old land areas have been explored a large number of deposits of beds of nodular phosphate have been found.

From the facts set forth in Dr. Penrose's report and the unpublished results of certain studies on swamps, we may draw certain general conclusions as to the best method of prosecuting the search for unknown deposits of American phosphates. These conclusions are essentially as follows:

First, as regards the superficial and recently formed deposits of phosphates. We are driven to the conclusion that this class of deposits may reasonably be sought for wherever soft calcareous beds containing a certain amount of lime phosphate have been subjected to long continued leaching by waters containing the share of carbonic acid gas which belongs to all rain-water after it has passed through the mat of decayed vegetation. As long ago as 1870 I became convinced that it was to the leaching out of the carbonate of lime by the carbonated water of the soil bed that we owe in the main the concentration of the nodular phosphates of South Carolina.[1] Although it is still necessary to explain

[1] See Proc. Boston Soc. Nat. Hist., vol. 13, 1871, p. 222.

many of the details of this process to adapt it to the peculiar circumstances of particular deposits, it seems to me that it is the key to the most common forms of superficial accumulations of nodular phosphates. In an admirable description of the phosphate beds in the neighborhood of Mons, in Belgium, by Mr. F. L. Cornet,[1] that distinguished author has independently propounded this simple hypothesis, and several other writers on the subject have apprehended the importance of this leaching action.

It is evidently essential to this process of concentration that the surface of the deposits which are leaching away should have been preserved from the action of mechanical erosion, which would have prevented the formation of phosphatic concentrates.

Inquiry into the conditions of the swamp deposits of this country has satisfied me that beneath the surface of many of our fresh-water marshes, and probably in a lesser degree beneath the marine deposits of the same nature, there is a more or less important concentration of lime phosphates constantly going on. The effect of this action is seen in the remarkable fitness of these fresh-water swamp soils for the production of grain crops. For instance, in the case of the Dismal Swamp district in Virginia and North Carolina we find that the soils on which the swamp deposit rests are extremely barren, while in the mud that has accumulated beneath the swamp we have a rich store of phosphates, potash, and soda, which causes the soil of these swamps to be extremely well suited to grain tillage as soon as it is drained. In a similar way in the swamps of New England and elsewhere we find the bog-iron ores which are frequently accumulated in their bottoms very rich in phosphatic matter. The evidence is not yet complete that this phosphatic material becomes aggregated into nodules in the swamp muds, but the number of cases in which nodules have been found in this position makes it quite likely that the nodulation of the material may go on in that position. The present condition of the inquiry goes, in a word, to show that wherever we have a region long overlaid by swampy matter we may expect a certain concentration of lime phosphates in the lower part of the marsh deposit. Wherever the swamp area lies upon somewhat phosphatic marls which have been slowly washed away by the downward leaching of the waters charged with the acids arising from decayed vegetation, or where the swamp deposits, even when not resting on such marls, are in a position to receive the waste from beds containing phosphates, we may expect to find a considerable concentration of phosphatic matter in the swamp bed. By the erosion of these swamps we may have the nodules of phosphate concentrated in beds such as occupy the estuaries of the rivers near Charleston, S. C.

The area of swamp lands which fulfill these conditions is very large. They exist in numerous areas in more than half the so-called Southern

[1] See Quart. Jour. Geol. Soc. London, vol. 42, 1886, p. 325.

States. At present it can only be said that they afford the conditions which, so far as the theory goes, should lead to the accumulation of phosphatic deposits of greater or less importance. It will be a simple matter to explain these deposits, though it is a task requiring a patient study of a large field. Although it is likely that the phosphatic materials will be found aggregated into nodules at many points in this area it will not be safe to assume that they will be found in the same form as those which occur about Charleston, S. C. The nodules found in the beds about the last named point, though in my opinion originating beneath swampy deposits, have apparently been, in part at least, swept from their original beds by the rivers which enter the sea at that point and have thus been concentrated in estuarine deposits.

Although local concentrations of phosphatic nodules other than those now known may well be sought for in the Southern States, I do not think that the precise conditions or character of the deposits as found at Charleston should be expected to repeat themselves elsewhere. It is characteristic of the process of concentration of phosphatic, as well as of other matter into nodules that the material takes on a great variety of aspects, each proper to a particular site, and this although the surrounding circumstances of the several localities may apparently be identical.

Next lower on the geologic section we have, in the Tertiary region of the Mauvaises Terres, extensive deposits of vertebrate remains which may possibly yield some commercially important supplies of bone phosphates. Although none of the existing sources of supply of these materials come from deposits of the nature of those found in Nebraska, the conditions of that remarkable region are so peculiar that it will not be well to pass it by without inquiry.

While the American Cretaceous deposits are, as a whole, decidedly different from those of the Old World, the Greensand beds of the section in the two countries present considerable likeness in their characters. It is probable that in this country, as in Europe, considerable parts of the Cretaceous section are somewhat phosphatic, and that those beds containing disseminated phosphatic matter have been in many places exposed to the process of leaching in former geologic periods. Therefore we may reasonably search in the Cretaceous beds of this country for the same class of phosphatic deposits which have proved so important in the northern parts of Europe.

Although some peculiar deposits of phosphate have been found in the Devonian rocks of Nassau, it may safely be assumed that below the line of the Cretaceous we have no facts to guide us in our search for phosphates until we come to the horizon of the Upper Silurian limestones, at about the level of the uppermost beds of the Upper Silurian, as far as that level can be determined by the perplexing assemblage of fossils. There occurs in Bath County, Ky., a thick bed of much decayed, very *phosphatic* siderite. This deposit covers but a small area and con-

sists of a patch of limestone about fifteen feet thick, which has been converted into siderite by the inleaching of iron-bearing waters from the ferruginous Ohio (Devonian) shales which formerly overlaid the bed. Since the escarpment of the Ohio shales retreated beyond this bed it has been subjected to oxidation and is now in the main converted into a much decayed limonite. Beneath this limonite there is a greenish, argillaceous sand which contains frequent nodules of lime phosphate. These nodules are smooth-surfaced and not unlike some of the nodules from the Carolina district. They contain as much as 92 per cent. of lime phosphate. It seems likely that these nodules were formed by the leaching out of the lime phosphate from the overlying ferruginous layers, which has completely removed the lime carbonate, but has not removed the whole of the less soluble lime phosphate (Fig. 1).

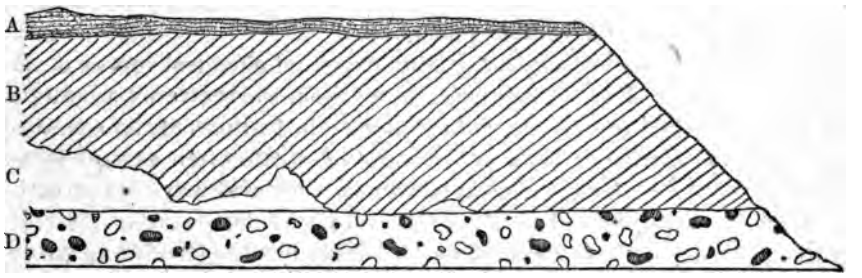


FIG. 1. Section at Olympia, Bath County, Ky. (Preston ore bed). A, soil; B, limonite iron ore; C, siderite iron ore; D, phosphatic nodules. Scale: 1 inch = 12 feet.

Although this deposit of nodules is not of sufficient abundance to have any economic value, it is clear that we have in it an indication of a method where, by a slight variation of the conditions, important beds of nodular phosphates might be found.

In the horizons of the Cambro-Silurian section, or, as it is generally called, the Lower Silurian, there is much greater reason to expect the occurrence of workable phosphates than in the beds immediately above. It is likely that the most important of the Spanish deposits belong in strata of this period, and the Welsh deposits of this general age are of noteworthy extent. We know, moreover, that the commoner marine animals of this part of the geological section were particularly adapted for the secretion of lime phosphate.

The search of this portion of the section for phosphates should be directed to two ends: first, to finding beds of very phosphatic limestone; and, second, to discovering veins formed by a segregation of lime phosphates either in the form of the Spanish deposits referred to by Dr. Penrose or in the condition of nodular accumulations. The area of rocks of these Lower Silurian and Cambrian periods in this country is very extensive, and so far there has been no search of them for phosphatic materials. The little work done in Kentucky during the above men-

tioned geological survey served only to show that the proportion of lime phosphate in the rocks is extremely variable, and that in certain beds it is so considerable that the material might advantageously be used in a local way for fertilizing purposes.[1]

The search for phosphatic materials in the stratified rocks demands a method of inquiry that has not yet been applied to the study of our rocks. It seems to me that the method, or rather methods, should be as follows:

First, there should be a careful inquiry to determine the share in which the several important groups of rock-making organic forms contribute phosphatic matter to strata. This can be accomplished by carefully comparing the chemical character of particular strata with the fossils the beds contain. When this determination is made we shall have one means of guiding our inquiries, which will surely be of great value in the search for bedded phosphates.

Secondly, we should have a carefully executed chemical survey of our stratified rocks. Enough can be gathered from the scattered records of chemical analysis to make it plain that certain features of the chemical character of particular beds or divisions of strata often extend laterally for great distances. This is shown in a general way by the character of the soils formed of the waste of particular horizons; for instance, the deposits of the horizon on which lies the Cincinnati group of this country and the equivalent deposits of Europe are nearly always well suited to grasses and grains and have a great endurance to tillage. It is now desirable to take these beds which promise to afford mineral manures and subject each stratum to analyses which shall determine the quantity of phosphoric matter, soda, and potash which they contain, so that their fitness for use as mineral manures may be ascertained.

Below the level of the Silurian and Cambrian strata, and partly in those sections where they have been much metamorphosed, lies the field of the vein phosphates. It is more than likely that in this vast thickness of rocks with their development in this country there are many extensive sources of this class of phosphates which await discovery. As yet no careful search has been made for such veins in any part of the United States. The regions most likely to contain such deposits are found in the central parts of the Appalachian system of mountains,

[1] Among the analyses recently made by the chemists of the Kentucky geological survey is one which indicates the presence of phosphoric acid in considerable quantities in the limestones of Coniferous age exposed at Stewart's mill, on Lulbegrud Creek, in Clark County. This partial analysis, for which I am indebted to Mr. John R. Proctor, the present director of the Kentucky survey, is as follows, viz:

Lime carbonate	21.380
Magnesia	3.055
Phosphoric acid	9.710
Potash	.830
Soda	.228
Siliceous nodules insoluble in acids	27.580

especially in the section from Virginia southward; in the Archæan district of Missouri and Arkansas, and in the vast region of highly metamorphic rocks of the Cordilleran district, extending from the Rocky Mountains to the Pacific Ocean. It is true that at present the economic value of phosphatic deposits in the western part of the continent would probably be small, on account of the great cost of transportation to the seaboard districts; but the growing use of phosphatic manures in the Mississippi Valley and the rapid exhaustion of the soils of that district will soon give commercial importance to any sources of supply of phosphates that may be found in any parts of the Cordilleras which are convenient to transportation.

A proper study of the mineral manures of this country can best be carried on by means of a well considered co-operation between geological explorers and the experiment stations of the several States. At present the methods of using mineral phosphates are extremely costly: not only is the material brought into the soluble condition by saturation in sulphuric acid, but it is then mingled with ammoniacal and other matter to increase its effect as a fertilizer. The result is that, although a ton of Carolina phosphate now costs but $6, the average price of the manufactured product to the consumer at the phosphate factories is about $30 per ton. It is probable that the essential value of the phosphatic ingredients to the plants of most soils is not enhanced by this costly treatment, though an incidental but dearly purchased gain, in the case of some crops, is obtained from the ammoniacal matter. The only effect of the superphosphatizing on the phosphatic matter is to make it more immediately absorbable by the plants. If placed on the soil without any other preparation than grinding, lime phosphate will slowly pass into a condition in which it may be absorbed by plants, while if treated with sulphuric acid it is for a time at least in a soluble state. That this treatment is not essential is well shown by the fact that the phosphatic matter derived from the rocks is brought into a condition for absorption by the ordinary process of decay in soils. Our present costly method of applying phosphates has come about through the commercial history of artificial manures, which is as follows:

Before guanos were brought into use the English farmers had learned that they could profitably use the phosphatic marls of their Tertiary and Cretaceous deposits without any artificial preparation. If guanos had not existed it seems likely that mineral phosphates would have always been used in this way. When the Peruvian guanos came into use they afforded a much more stimulating material than any other purchasable manures, and in a short time they established the type of commercial fertilizers. When the sources of supply of these guanos became in part exhausted, artificial compounds, formed on a basis of rock phosphates or apatites, were devised to take their place. These were made to imitate the effect of the guanos as closely as possible. Like them, they

gave a quick though temporary stimulus to the soil, enabling the farmer to obtain the greater part of the return for his investment in the season following the application of the high priced manure. Very generally the fertilizer, guano or compounded material, was applied with the seed or dibbled in the soil alongside the young plant, so that it would be immediately available in the first stages of its growth, and, what is a more important consideration, that it might take less of the substance to give the effect than if it were sown broadcast over the surface or mingled with the soil of the whole field.

In this way a habit has been established in the art of using phosphates, as well as in the composition of the material, which, like all commercial habits, is hard to overcome. The question to be determined is as to the utility of phosphates with other modes of treatment than those which are applied to the imitation guanos. At present this treatment requires the commingling of the lime phosphate with a number of costly substances. The manufacture can only be advantageously carried on at points remote from the districts where the materials are produced and remote from the fields where they are used, so that the costs of transportation are great. The problems to be solved by the agricultural stations are as follows:

(1) As to the effect, immediate as well as permanent, arising from the application of ground phosphatic rock commingled with other materials on soils used for the production of different crops.

(2) As to the degree of comminution of the material which is most advantageous. It seems possible that fine pulverizing may take the place in a measure of superphosphatizing.

(3) As to the effect of mingling the powdered rock with ordinary barn yard manure, peat, and other similar substances.

(4) As to the effect of lime phosphate used alone on soils containing different mineral constituents, as, for instance, those having considerable proportions of lime carbonate and those having but little of that substance.

(5) As to the proportion of the lime phosphate which it is necessary to apply in order to produce different degrees of effect upon the fertility of soils.

It is desirable that these and other experiments should be tried at a number of stations in different parts of the country, in order that the needs of various crops may be considered and the effect of the fertilizers on different classes of soils ascertained.

The effect of a small amount of lime phosphate on the fertility of the soil is clearly great, but so far we do not know with accuracy the amount necessary to produce a given effect. The range in phosphoric acid contents in the soils of Kentucky, as determined from many hundred analyses, varies from 0.540 to 0.061.[1] In most cases the fitness of the

[1] See report of Dr. Robert Peter in Repts. Geol. Survey Kentucky, new series, vol. 5, 1878, N. S. Shaler, Director.

soil for grain tillage is measurably proportionate to the phosphatic contents. It seems almost certain, though not yet demonstrated, that the greater part of the phosphatic matter in the soil is in the state known as *insoluble*, and that it only becomes in small part, year by year, soluble, or, in other words, fitted for assimilation by plants. Whenever the soil contains the quantity of lime which characterizes the better class of Kentucky soils it is supposed that even if soluble phosphatic manures are applied the superphosphate becomes again insoluble by taking up a molecule of lime. It is therefore an interesting question as to the means by which the lime phosphate enters the plants. It may be that the solution is effected through the action of the various humic acids of the soil or it may arise from some specific change which takes place at the contact of the soil with the roots. It is evident that this point requires precise determination, for on it will depend further experiments as to the methods of applying phosphatic manures.

There is yet another point on which we need experiments. Many of our rock phosphates, especially those which are distinctly bedded, contain low percentages of phosphatic matter. Many of our lime phosphates contain crystals of apatite and calcite so intermingled that it is not possible to separate them; yet from these deposits it will be easy to produce a mixture of lime carbonate and lime phosphate containing from 10 to 20 per cent. of phosphoric acid. The value of such material for manure has never been determined. If it can be used in a way which will give to the fields the full value for both the lime and the phosphorus it will open a way for an extensive production of cheap fertilizers.

The foregoing considerations give the general results of the preliminary inquiry into phosphatic manures of which Dr. Penrose's work forms a part. Before we go further into these studies I much desire to have the criticism and advice of others who have considered this subject. It is with this view that I have ventured to give in the foregoing pages an account of the aim of the inquiries I have in hand. The questions are at once chemical and geological, and demand much co-operation for their solution. Much of the work of searching for the unknown phosphatic deposits of this country will necessarily have to be undertaken by local students of geology or by commercial explorers in search of such deposits. Unfortunately, the unfamiliar aspect of the various forms of phosphatic deposits will make this task under any circumstances difficult. There is no substance of equally wide diffusion among those of considerable commercial importance which, in the present state of popular knowledge, so readily escapes detection as lime phosphate. It may be hoped that the following memoir may make it easier for explorers to recognize this class of deposits.

My own as well as Dr. Penrose's acknowledgments are due to many persons who have given him aid in the prosecution of his work. To Prof. Charles U. Shepard, jr., of Charleston, S. C., Dr. Penrose is par-

ticularly indebted for much information and access to a great deal of valuable matter contained in his unpublished notes on American and foreign phosphatic deposits.

In justice to Harvard University it should be said that the following report, although designed as a memoir of the U. S. Geological Survey, was used in manuscript form by Dr. Penrose as his thesis for the degree of doctor of philosophy in that institution.

NATURE AND ORIGIN OF DEPOSITS OF PHOSPHATE OF LIME.

By R. A. F. PENROSE, JR.

IMPORTANCE OF PHOSPHATE OF LIME IN NATURE.

Phosphorus is one of the most universally distributed of all the elements. It is found in all animal and vegetable matter, as well as in most eruptive and sedimentary rocks. Phosphoric acid composes over 40 per cent. of the ashes of bones and in the vegetable kingdom it is especially abundant in the seeds of plants. Thus the ash of wheat contains over 49 per cent. of phosphoric acid.

It has been estimated that for each cow kept on a pasture through the summer there are carried off, in veal, butter and cheese, not less than fifty pounds of phosphate of lime. Consequently it will be seen that phosphoric acid is one of the most important elements of plant food, and no soil can be productive which is destitute of it. The necessity of restoring phosphoric acid to an exhausted soil has been acknowledged from very ancient times, though the cause of its stimulating effect was unknown until a comparatively late date. In the days of the Romans the excrements of birds, from pigeon-houses and bird-cages, brought a high price, and Edrisi relates that the Arabians, as early as 1154 A. D., used the guano deposits found along their coast for agricultural purposes. Garcilaso de la Vega (Comentarios Reales, lib. V, 1604) says that the Peruvians, in the twelfth century, used the guano beds on their islands as fertilizers. Of such importance did they esteem the material of these beds that the penalty of death was imposed by the early Incas on any one found killing the birds that made these precious deposits. It was not, however, until the early part of this century, when Liebig and others showed the important part played by phosphoric acid in vegetable life, that artificial phosphatic manures came into use, and it is only in the last twenty years that the mining of natural phosphates with their conversion into superphosphates has assumed its present great and steadily increasing importance.

CLASSIFICATION OF DEPOSITS OF PHOSPHATE OF LIME.

The classification of deposits of phosphate of lime is a matter attended with many difficulties, not only on account of the great variety of forms in which phosphate of lime occurs, but also because many varieties grad-

ually blend into one another, thus often rendering it uncertain to which class a special deposit should be referred. The classification given below is based mainly on the chemical composition of the deposits. These are grouped under two principal headings, namely, *mineral phosphates* and *rock phosphates*.[1] The former includes all deposits of phosphate of lime which, besides having the other properties inherent in a true mineral, have a definite chemical composition or at least show a strong tendency toward such properties and composition. The latter includes those deposits which, having no definite chemical composition and lacking the homogeneous nature and other fixed characteristics of a true mineral, cannot be classed with mineral phosphates. These two classes are again subdivided as follows:

- Mineral phosphates.
  - Apatites.
    - Fluor-apatites.
    - Chlor-apatites.
  - Phosphorites.
- Rock phosphates.
  - Amorphous nodular phosphates.
    - Loose nodules.
    - Cemented nodules or conglomerates.
  - Phosphatic limestone beds.
  - Guanos.
    - Soluble guanos.
    - Leached guanos.
  - Bone beds.

The various phosphate deposits of North and South America, Europe, Africa, and other localities will be treated under the different divisions of the above classification, each deposit being described under the heading to which it belongs. Mineral phosphates will be taken up first, and then the various representatives of rock phosphates will be described. Special attention will be given to the phosphate deposits of the United States and Canada, which were visited and studied by the writer.

MINERAL PHOSPHATES.

APATITES.

Apatite is found in both stratified and crystalline rocks, but is much more plentiful in the latter, especially in metamorphic limestone, syenite, garnetiferous, hornblendic, and pyroxenic, gneiss, mica-schist, and igneous and volcanic rocks.

The mineral occurs in both the massive and the crystalline form. It belongs to the hexagonal system of crystallization, has a vitreous or subresinous luster, is translucent and sometimes transparent, has a hardness of 5, a specific gravity of 3.17 to 3.25, is brittle, of a white, yellow, green, or red color, gives off phosphorescent light when heated,

[1] It will be seen that the determination which phosphate shall be classed under minerals and which under rocks must in certain cases be somewhat arbitrary, but the classification is intended simply as a matter of convenience in describing the various deposits, and as such answers its purpose sufficiently well.

and becomes electric by application of heat or friction. It occurs principally in the early crystalline rocks and is found in New York, New Jersey, Maine, Canada, and other places in North America. In Europe it is found in England, France, Saxony, Tyrol, Bohemia, Spain, Norway, and many other regions. The only deposits of economic importance as yet discovered are in Canada, Norway, and Spain.

Prof. J. D. Dana gives as a formula of apatite $Ca_3O_8P_2+\frac{1}{3}(Cl_2F_2)$, in which the fluorine and the chlorine may replace each other in any proportion. When there is more fluorine than chlorine present the mineral is called fluor-apatite, and when less it is called chlor-apatite.[1] The apatites of Canada and of Spain, as well as most of those from Norway, are essentially fluor-apatites, though they almost always contain 0.01 to 0.5 of chlorine. Occasionally apatites are found free from chlorine, as some of those of Nassau and the Tyrol, but they are never found entirely free from fluorine. The apatite of Snarum, Norway, contains more chlorine than any other known apatite, amounting, as it does, to 2.71 per cent. of that element.[2] The apatite deposits of Canada, being at present more extensively worked than any others and consequently better known, will be described first; after them the apatites of Norway and Spain.

APATITES OF CANADA.

Phosphates were discovered in considerable quantities in Canada before the middle of this century, and were described by Dr. T. Sterry Hunt in the Canadian Geological Survey Reports for 1848. Shortly afterwards they were mined in the counties of Lanark and Leeds, Ontario. But the first regular mining operations of any considrable importance were begun in 1871, in the townships of Buckingham and Portland, Ottawa County, Quebec, where apatite had been discovered several years later than in Ontario. The first company to operate on a large scale here was known as the Buckingham Mining Company. It worked successfully until 1875, when a sudden fall in the prices of the phosphate market led to a stoppage. For several years after this the mines were worked by private parties, until, in the years 1881 to 1883, the large mining companies which now control the richest properties in Canada were organized. Many of the phosphate properties in Ontario have been worked by the so-called "contract system." Under this system the farmers of the neighborhood, whenever they are without employment, blast out a little phosphate. The result of such a method is, of course, that the whole of a property is soon cut up with small pits and trenches, rarely exceeding twenty feet in depth, and often interfering considerably with later and larger mining operations.

There are two principal districts in Canada where apatite occurs in considerable quantities. The first is in Ottawa County, Province of Que-

[1] J. D. Dana: Manual of Mineralogy and Lithology, 1885, p. 213.

[2] O. Ramon T. Muños de Luna: Estudios químicos sobre economía agricola en general, y particularmente sobre la importancia de los abonos fosfatados.

bec. It consists of a belt running from near the Ottawa River, on the south, for over sixty miles in a northerly direction, through Buckingham, Portland, Templeton, Wakefield, Denholm, Bowman, Hincks, and other townships. The belt probably stretches still farther to the north, but the country in that direction has been but little explored, and is scarcely known, except to trappers and Indians. The belt averages in width from fifteen to twenty-five miles.

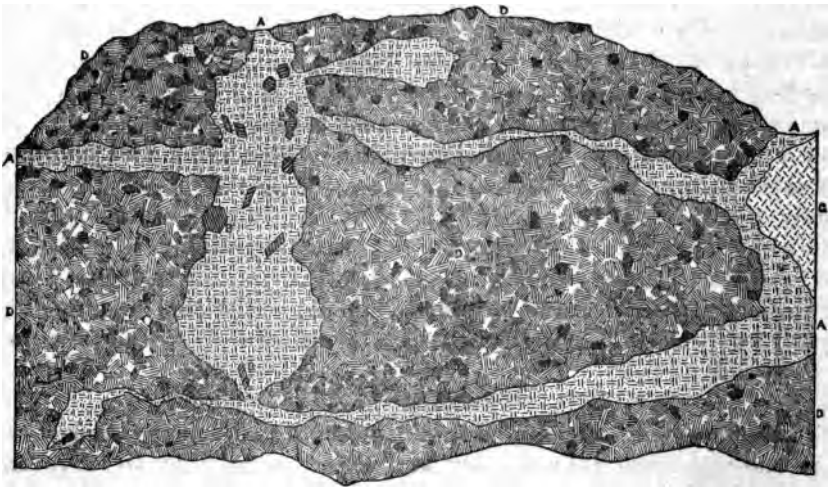


FIG. 2. Apatite in the Bonanza pit, Union mine, Portland, Ottawa County, Quebec, Canada. A, apatite; B, mica; C, white feldspar; D, pink and white feldspar, mica, and pyroxene. Scale: 1 inch = 16 feet.

The second phosphate district is in Ontario, principally in the counties of Leeds, Lanark, Frontenac, Addington, and Renfrew. This district is much larger than that of Quebec. But the apatite is much more scattered, and, though special deposits are in some places much more continuous than those of Quebec, the mineral has not yet been discovered in such large pockets as occur in the latter district. The belt which contains the deposits runs from about fifteen miles north of the St. Lawrence River in a northerly direction to the Ottawa River, a distance of about one hundred miles. It varies from fifty to seventy-five miles in breadth.

The above-mentioned districts are the regions where apatite has been found most plentifully, but it also occurs in other places, though, so far as has been discovered, in much smaller quantities.[1]

The apatite occurs in the upper part of the Lower Laurentian formation, the horizon being characterized by large quantities of pyroxene rock. The principal phosphate-bearing band consists of quartzites, gneisses, schists, feldspar, and pyroxenic and calcareous rocks, having an aggregate thickness, according to Vennor, of twenty-six hundred to

[1] Lately it has been found that apatite is very generally distributed in Pontiac *County, Quebec.*

thirty-nine hundred feet. All the beds are more or less completely metamorphosed, being sometimes indistinctly stratified and at other times massive and with no traces of bedding. The rocks, often contorted, all dip at a vertical or almost vertical angle. Sometimes the gneiss contains large quantities of mica and has a distinctly foliated structure. At other times it is impregnated with large quantities of pyroxene, as in the Quebec district. In the Ontario district this pyroxene is often replaced by hornblende of a dark-green, lustrous character. A highly garnetiferous gneiss is also often found in large quantities in some of the apatite localities. In the Quebec district there is a series of trap dikes running in a general east and west direction. By some they are supposed to be connected with the occurrence of the apatite. But the trap is, probably, of a later date than the apatite, as it is sometimes found passing through pockets of that mineral (Fig. 4).

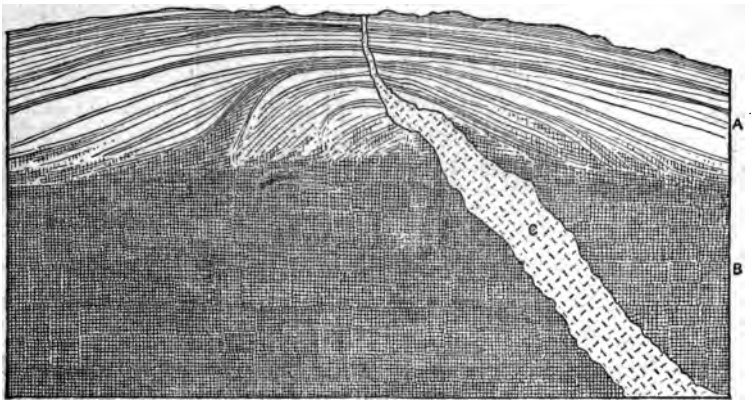


FIG. 3. Section on south side of hill on north side of Rheaumo Lake, Templeton, Ottawa County, Quebec, Canada. A, stratified rock; B, pyroxene; C, feldspar. Scale: 1 inch = 16 feet.

The principal difference between the country rock of the Quebec district and that of the Ontario district is that the rocks in the latter region are often much more hornblendic than those in the former, and are often found in the form of a more or less hornblendic gneiss. The country in the Quebec apatite district is rough and mountainous. The hills are of a remarkably uniform height, rarely rising over five hundred to six hundred feet above the level of the neighboring Du Lièvre River. In Ontario, on the other hand, the land in Leeds, Lanark, Frontenac, and Addington Counties is low, and sometimes shows a smooth, glaciated surface, covered by a thin layer of soil. In Renfrew County, however, the land is more hilly, and resembles that of the Ottawa district. As before remarked, the apatite occurs, almost without exception, in association with pyroxenic or hornblendic rocks. This rule holds especially true in the Quebec district,

where the phosphate has never yet been found without being associated with pyroxene rock, possibly often of vein origin. This, called pyroxenite by Prof. T. Sterry Hunt, occurs in ridges, running in a general northeast and southwest direction, following the general course of

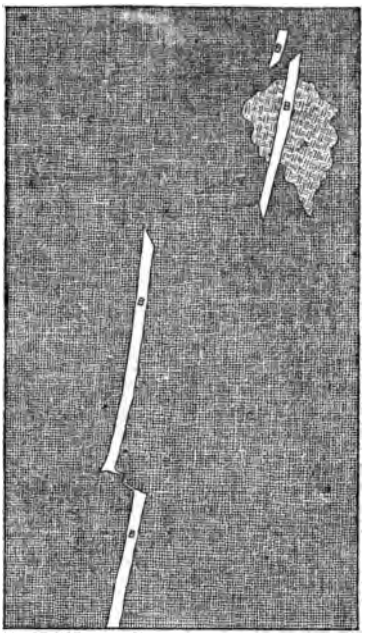


FIG. 4. Dike at Union mine, Portland West, Ottawa County, Quebec, Canada. A, apatite; B, trap; C, pyroxene.

the strike of the country gneisses. It forms, together with lilac-colored orthoclase, quartzite, and trap, the mass of many of the hills in the phosphate district, while the stratified and massive gneisses are often seen bordering the sides of the ridges, as shown in Fig. 5.

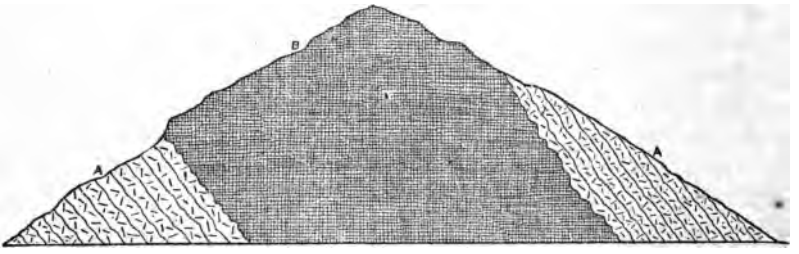


FIG. 5. Ideal section southeast and northwest through the Emerald mine hill, Buckingham, Ottawa County, Quebec, Canada. A, country quartzite, gneiss, etc.; B, pyroxene. Scale: 1 inch = 180 feet.

The pyroxene rock is never found distinctly bedded, though occasionally a series of parallel lines can be traced through it, which, while possibly the remains of stratification, are probably often joint planes. Sometimes, when the pyroxenite has been weathered, apparent signs of bed-

ding are brought out, which are often parallel to the bedding of the country rock. Thus at Bob's Lake mine, in Frontenac County, a rich-green pyroxenite occurs which exhibits this structure. For 10 feet down from the surface this apparent bedding can be distinguished. It gradually grows fainter, until it disappears in the massive pyroxenite below. A similar phenomenon has been observed at the Emerald mine, Buckingham Township, Ottawa County, Quebec, and at several other places (Fig. 6). It can also be seen in the crystalline rocks on Newport Island, opposite Tiverton, R. I. There, for a depth of from one to two feet, an apparent stratification can be seen, and the rock below gradually becomes more massive, until it merges into the apparently homogeneous mass of the hill.

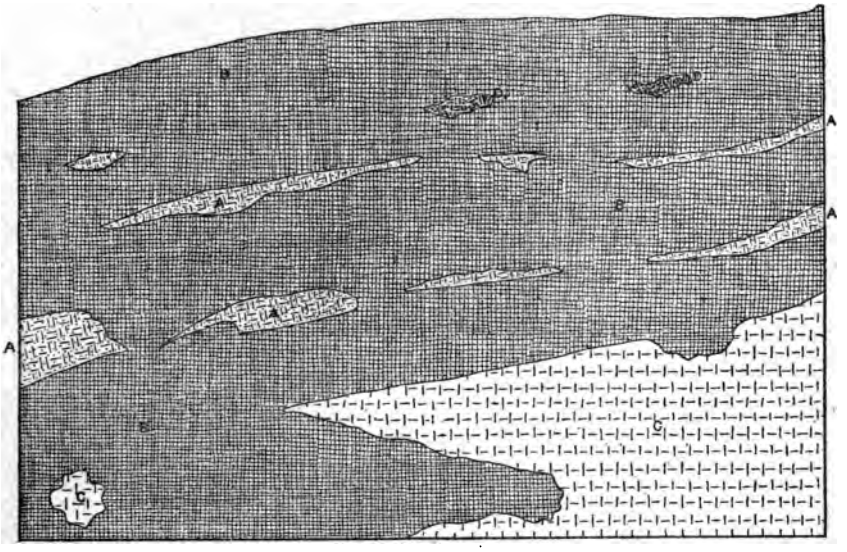


FIG. 6. Section in a pit near the Emerald mine (looking west), Buckingham, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene; C, feldspar; D, pyrite. Scale, 1 inch = 6 feet.

The pyroxene occurs in several different forms. Sometimes it is massive, of a light or dark green color, and opaque or translucent; at other times it is granular and easily crumbled. Occasionally it occurs in a distinctly crystalline form, the crystals being in color of different shades of a dull green, generally opaque or translucent, but sometimes, though rarely, almost transparent. The massive variety is the most common, and composes the greater part of the pyroxenites found in the phosphate districts.

The associated feldspar is generally a crystalline orthoclase, varying in color from white to pink and lilac; occasionally, as in Denholm and Bowman Townships, Ottawa County, Quebec, it occurs as a whitish-brown, finely crystalline rock. The trap is of the dark, almost black, variety. Thin sections under a microscope show it to have a very

variable composition—a net-work of striated blades of triclinic feldspar, brownish augite, black opaque grains of magnetite, and, commonly, small quantities of a green, chloritic mineral.[1] The quartzite is white, gray, or blue. The blue variety often contains specks of felsite. These pyroxenes, feldspars, and quartzites are often mixed up in a perfect net-work, very similar to that seen at Marblehead, Mass., and at

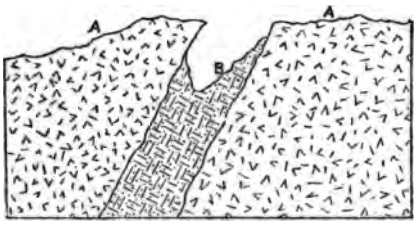


FIG. 7. Section of apatite vein near Smith's mine, Oso, Frontenac County, Ontario, Canada. A, country syenite; B, red and green apatite. Scale: 1 inch = 8 feet.

many places in the metamorphic rocks of Mount Desert Island. Often whole hills are formed of these rocks, mixed in various proportions (Figs. 8 and 9). The gneiss in some places has no distinct line of separation from the pyroxene, but seems to have been impregnated with some of it, forming for a few feet from the line of contact a more or less pyroxenic gneiss, which is easily decayed and eroded by weathering (see Fig. 3).

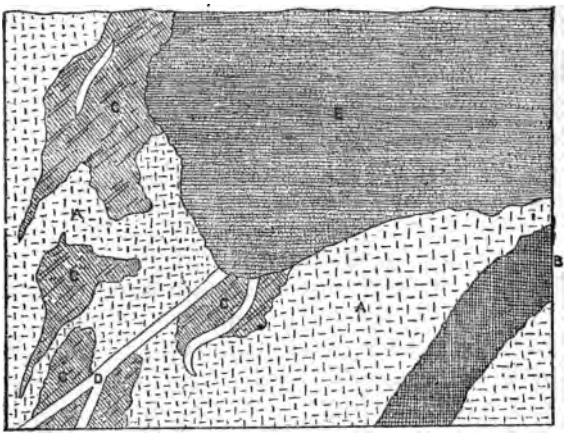


FIG. 8. Horizontal view of surface rock at Turner's Island, Clear Lake, Canada. A, feldspar; B, pyroxenite; C, hornblende; D, feldspar dykes; E, soil. Scale: 1 inch = 6 feet.

In the Ontario district, as mentioned before, the pyroxene is often replaced by hornblende. Thus at Bell's mine, in Frontenac County, little or no pyroxene is met with, and in its place large quantities of dark *green* hornblende occur. The apatite here is found in a rock consisting

[1] *B. J. Harrington*: Geol. Survey Canada, Rept. Progress, 1877–'78.

of green hornblende and white feldspar, which forms a ridge about one hundred yards wide parallel to the strike of the country gneiss. To complete the list of rocks found in the apatite districts it is necessary to mention the large veins of crystalline calcite, which often contain serpentine and chrysotile. In the occurrence of these veins this Canadian apatite region is in marked contrast with that of Norway, where little calcareous matter is found.

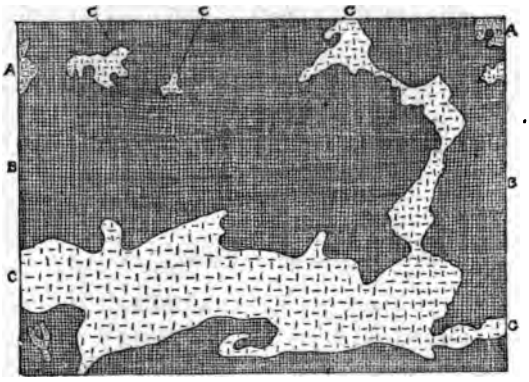


FIG. 9. Pyroxene surface, Star Hill, Union mine, Portland, East Ottawa County, Quebec, Canada. A, apatite; B, pyroxene; C, feldspar. Scale: 1 inch = 8 feet.

The apatite of Canada is found occurring in a great variety of ways. Prof. T. Sterry Hunt regards most of the workable deposits as veins, but he thinks there are also some deposits which occur in beds. He has discovered small masses of apatite marking the lines of stratification in

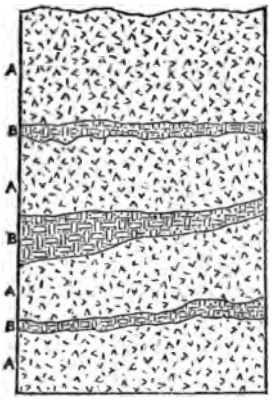


FIG. 10. Opening in west side of a hill near Smith's mine, Oso, Frontenac County, Ontario, Canada. A, country syenite; B, apatite. Scale: 1 inch = 24 feet.

the pyroxene.[1] An instance of this was seen by the writer in an old pit in Buckingham Township, Ottawa County, Quebec, where the apparent lines of stratification were marked by bands of apatite (see Fig. 6).

[1] Geol. Survey Canada, Rept. Progress for 1863.

Professor Hunt thinks that most of the deposits of apatite are concretionary vein stones and have resulted from a hot-water solution. He bases his belief upon several characteristic facts concerning Canada apatite, such as the rounded form of many of the apatite crystals, which

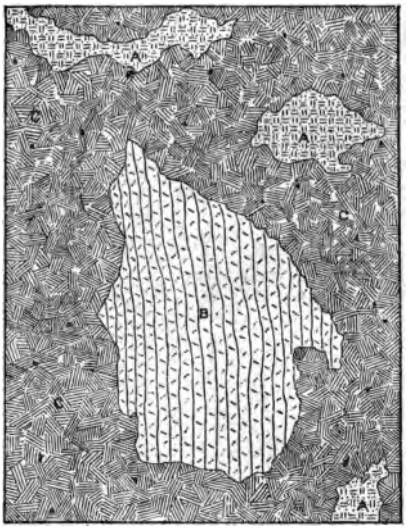


FIG. 11. Bowlder of country rock embedded in pyroxene etc., High Rock mine, Portland West, Ottawa County, Quebec, Canada. A, apatite; B, country gneiss; C, mica, pyroxene, and feldspar. Scale: 1 inch = 6 feet.

he regards as due to the action of partial solution after deposition, and not of fusion, as suggested by Dr. Emmons.[1] Another argument is that one mineral in the vein is often found incrusting or containing frag-

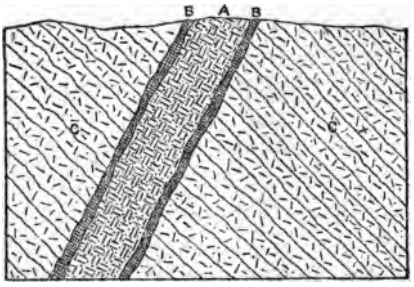


FIG. 12. Section of one of the northwest and southeast veins at Foxton's mine, Loughboro', Frontenac County, Ontario, Canada. A, apatite; B, pyroxene; C, country gneiss. Scale: 1 inch = 7 feet.

ments of another. Thus it is very common to find masses of crystalline calcite rounded into pebbles and buried in the centers of apatite crystals, which are themselves worn and rounded, showing, as Dr. Hunt

[1] Nat. Hist. New York, pt. 4, Geology, 1843, pp. 57, 58. Some of the dike stones of eastern Massachusetts, especially those in the town of Somerville, contain phosphate *crystals which are similarly* rounded.—N. S. S.

thinks, that the erosive action in the veins has taken place in at least two different epochs. The appearance in the veins of drusy cavities and the parallel deposition of the different minerals observed in many veins are also arguments for the theory of concretionary structure. Professor Dawson thinks that many of the deposits of the Ontario district are true beds.[1]

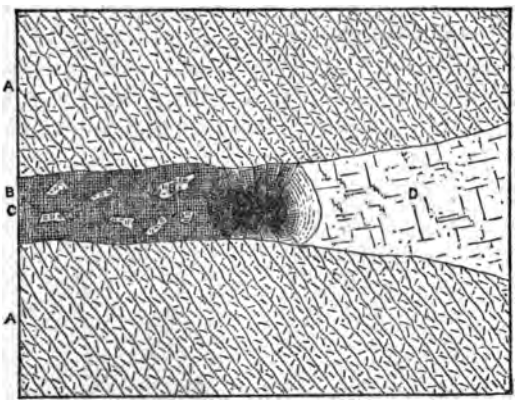


FIG. 13. Horizontal section showing natural cavity in vein, Loughboro', Frontenac County, Ontario, Canada. A, country gneiss; B, apatite; C, pyroxene; D, calcite. Scale: 1 inch = 7 feet.

Prof. B. J. Harrington[2] thinks that most of the phosphate deposits will come under the heading of fissure veins and pockets. He shows that many of the deposits cannot be beds, because they cut across the strata of the country rock.

Many of the veins are of considerable length. A very continuous vein, composed of hornblende, calcite, and apatite, mixed in varying proportions and associated with sphene, zircon, mica, scapolite, etc., is found in Renfrew County, Ontario. This vein, or what may be a series of similar and parallel veins, was traced by the writer for a distance of three miles, and it is said by the native prospectors to be traceable for 27 miles. It runs in a N. 40° E. direction, widening and contracting at intervals and varying from three to thirty feet in thickness. It can best be examined on Turner's Island, in Clear Lake, Renfrew County, Ontario, where several small openings have been made in it for the purpose of mining the rich apatite found there.[3] The island is three-quarters of a mile long and from one hundred feet to a quarter of a mile wide. The vein runs through its longer axis from one end to the other. The apatite occurs in crystals, sometimes in considerable quantities and composing the greater part of the vein matter and at other times

[1] Quart. Jour. Geol. Soc. London, vol. 32, 1876, p. 289.

[2] Geol. Survey Canada, Rept. Progress for 1877–'78–'79.

[3] The same or a similar vein is seen to great advantage on the land of Xavier Plaunt, on the south side of Clear Lake. It widens and contracts at intervals and runs in the same general direction as the Turner's Island vein.

scattered sparingly through a mass of the crystalline minerals which accompany it. Apatite crystals of immense size have been found here. One prism is said to have weighed seven hundred pounds; a crystal of zircon, almost a foot in diameter, is also said to have been found in the same vein. A crystal of sphene from this locality in the Harvard Mineral Cabinet measures over a foot in length. The country rock on the island consists of a confused mass of feldspar, coarse-grained, unstratified gneiss, and of a rock composed of feldspar and hornblende. Small quantities of green pyroxene are also found (see Fig. 8). The vein is said to change into pure calcite at its extremities. It shows no signs, as far as seen, of banded or concretionary structure, but consists of a mass of crystallized minerals mixed in an apparently indiscriminate manner.

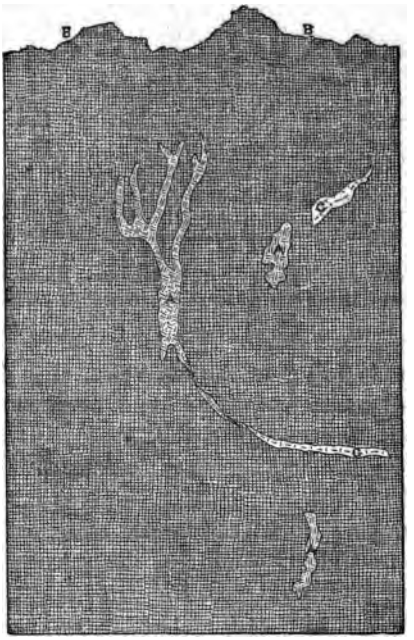


FIG. 14. Northeast side of a pit in the North Star mine, Portland East, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene; C, feldspar. Scale: 1 inch = 10 feet.

Like most apatite deposits in Canada, the vein has no sharp line of division from the country rock, but gradually blends into it. The hornblende in the country rock becomes more perfectly crystalline and occurs in larger masses as the vein is approached, until finally, when the vein is met, the hornblende and the feldspar crystallize out separately among the other minerals. "Such a blending of a vein with the walls," says Professor Dana, "is a natural result when its formation in a fissure takes place at a high temperature during the metamorphism or crystallization of the containing rock."[1] This blending of the country rock with the vein matter does not, however, always happen, as sev-

[1] Dana's Manual of Geology, 1875, p. 733.

eral cases were found where the apatite and associated minerals came into direct and sharp contact with the country rock (see Figs. 7 and 20). Thus, on the land of the Sly brothers, in Oso, Frontenac County, Ontario, there is a vein two feet wide in a gneissic rock. The boundary lines of the vein are sharply defined and white, red, and transparent calcite is associated with grass-green hornblende and brown apatite, in a mass apparently devoid of any banded structure (see Fig. 7). The vein dips at an angle of 85° N. and strikes E. and W. The country rock strikes N. 20° E. and dips 40° to 45° ESE. A somewhat similar instance is seen in the same township at Boyd Smith's mine. Here were three veins apparently occupying joint planes, and parallel to one another (see Fig. 10). The veins are composed principally of apatite and hornblende, and their general character is very similar to that of the last vein described. They strike N. 15° W. and dip at 10° NE. The strike of the country gneiss is N. 35° E., dip 60° SE., so that it is evident that the deposits cannot be beds. They can be traced for 50 yards along the side of the hill.

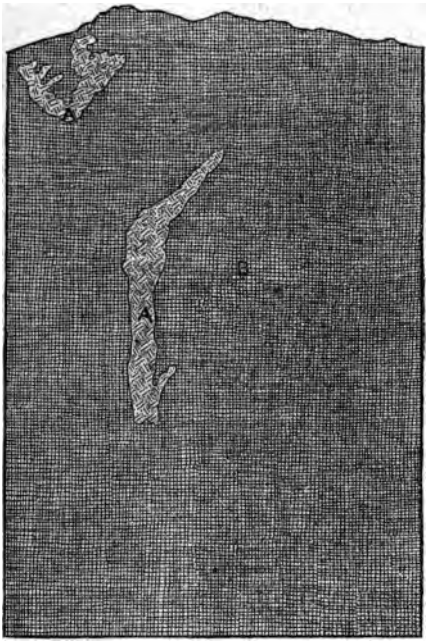


FIG. 15. Southwest side of a pit at North Star mine, Portland East, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene. Scale: 1 inch = 10 feet.

Some of the veins of apatite show a distinctly banded structure. On the land of James Foxton, in Frontenac County, township of Loughboro', there is a series of gash-veins running in a general northwest and southeast direction. They are of all sizes, from small ones not two inches thick to large ones three to six feet wide. The general character of all of them is the same. They occur in the country gneiss and occupy an al-

most vertical position. Fig. 12 shows a section of one of them, and most of the others are like it. It will be seen that the pyroxene lines both sides of the vein and the apatite comes in the middle. The strike and the width of nine of these veins were found to be:

N. 11° W., six inches wide. Red apatite.
N. 10° W., eighteen inches wide. Red apatite.
N. 8° W., one to three feet wide. Red apatite.
N. 20° W., one foot wide. Red apatite.
N. 8° W., one foot wide. Red apatite.
N. 35° W., six inches to one foot wide. Red apatite.
N. 36° W., one foot wide. Red apatite.
N. 45° W., one foot wide. Red apatite.
N. 30° W., one foot wide. Red apatite.

The country gneiss is much contorted and strikes in various directions. It has an almost vertical dip. On the same properties there are also other veins running in various directions, but they are generally of small extent. In one place a vein was seen composed on one side of a band of apatite and on the other of a band of pyrites of iron containing masses of talc.

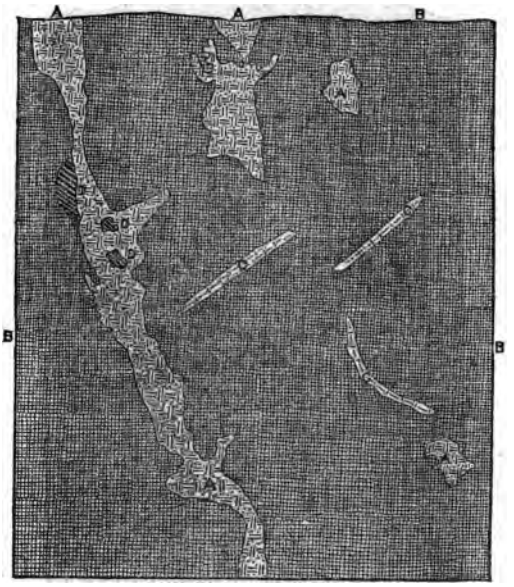


FIG. 16. Southeast side of a pit at North Star mine, Portland East, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene; C, feldspar; D, mica. Scale: 1 inch = 10 feet.

Another instance of a banded vein occurs at Mud Lake, Templeton Township, Ottawa County, Quebec, where apatite, mica, and pyroxene form the contents of the vein.[1] But it is generally in the Ontario district that the banded structure is most often seen.

In the township of North Burgess, Lanark County, Ontario, are many examples of phosphate-bearing veins, some of which can be traced for

[1] *B. J Harrington*: Geol. Survey Canada, Rept. Progress for 1877–'78–'79.

over half a mile, while others are short and amount to little more than pockets. In places the ground is literally cut up by a net-work of these veins, varying from a few inches to over ten feet wide. Occasionally they

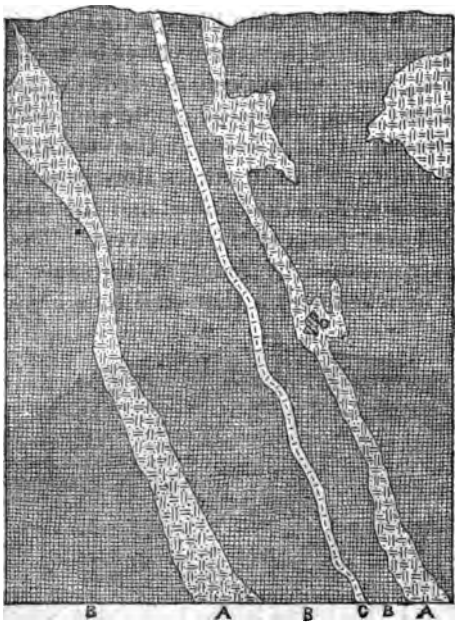


FIG. 17. Northwest side of a pit at North Star mine, Portland East, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene; C, feldspar; D, mica. Scale: 1 inch = 10 feet.

are found widening into bunches almost twenty feet across. The veins often show a banded structure and consist of mica and pyroxenite on the outside and apatite in the center. The outside bands of the veins are in some cases composed of a dark, almost black, talcose material.

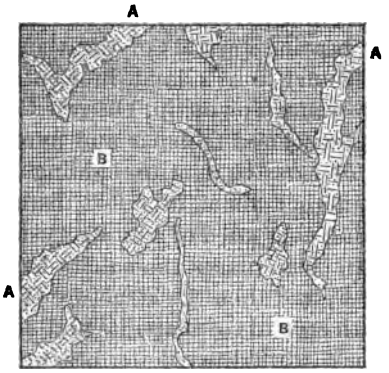


FIG. 18. Part of the northeast wall of McLaurin's mine, Templeton, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene. Scale: 1 inch = 5 feet.

In other places the contents of the vein consist of apatite, mica, pyroxenite, and white and flesh or salmon colored calcite, indiscriminately

mixed and associated with small quantities of scapolite, zircon, sphene, talc, hornblende, specular iron ore, zeolites, and other minerals. Veins also occur which are almost entirely composed of apatite crystals scattered in a matrix of granular quartzite.

On the land of the Anglo-Canadian Phosphate Company, at Otty Lake, North Burgess, where some of these veins have been opened to a depth of seventy to eighty feet, the mode of occurrence of the apatite is well seen. The prevailing country rock here is quartzite and garnetiferous gneiss. In some cases the line of division between the vein matter and the country rock is sharply drawn, while in others they gradually blend. Both of these phenomena, as well as the banded and the unbanded structure, are often seen in different parts of the same vein. The apatite occurs in bunches, sometimes connected by seams of the same mineral. From a single one of these bunches over a thousand tons have been taken.

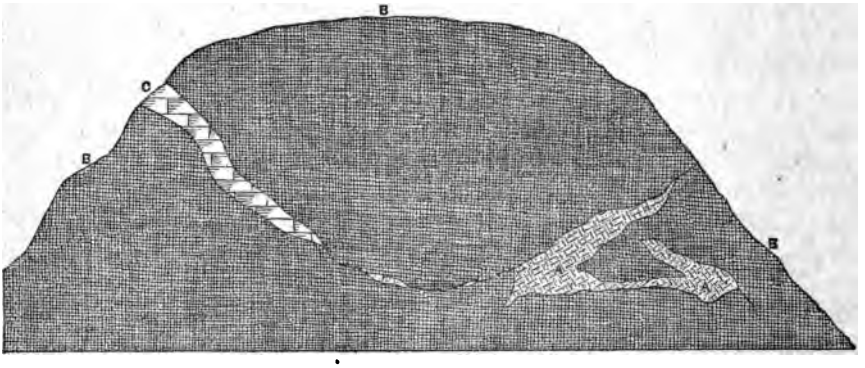


FIG. 19. Section at McKenzie's opening, looking ENE., Bowman, Ottawa County, Quebec, Canada. A, apatite, with pyroxene crystals; B, pyroxene; C, limestone. Scale: 1 inch = 50 feet.

The contents of the phosphate-bearing veins are often very variable at different points in the same vein, sometimes consisting mostly of apatite, scapolite, feldspar, and pyroxene, and at others being composed of crystalline limestone bearing crystals of the above minerals. Such a formation is seen on Henry Barr's land, in Renfrew County. At the McKenzie mine, in Bowman Township, Ottawa County, Quebec, there is a vein in a hill of lilac-colored feldspar and pyroxenite. One part of the vein is composed of massive apatite, holding crystals of pyroxene and scapolite, while another about fifty feet distant assumes a totally different character, being composed of a pink, crystalline calcite, bearing crystals of apatite. In some places the calcite has been worn away by the infiltration of water, and then the structure of the vein can be seen. The cavity is lined with crystals of scapolite and pyroxene, which come next to the country rock, while the calcite, bearing the crystals of apatite, comes in the middle (Fig. 19). This formation of drusy cavities in limestone leads is very common, especially in the Ontario district. Often the calcareous matter has been washed away, and crystals of apatite *and their fragments* are scattered over the bottom of the hollow. The

formation of cavities seems especially apt to take place at the point of junction of the limestone and a harder mineral in the vein. Thus in the township of Loughboro', Frontenac County, Ontario, was seen the cavity represented in Fig. 13, where a mass of limestone in a vein came in contact with a mass of apatite-bearing pyroxenite. From this opening several hundred pounds of loose apatite crystals were taken. Though it will thus be seen that the apatite of Canada often occurs in well defined veins, yet the largest deposits yet discovered occur in irregular masses in the pyroxenic and feldspathic rocks (see Figs. 2, 14, 15, 16, 17, 18, and 21). They seem to occur at some places in fissures and at others as simple segregations. As a general rule it may be said that the vein character is best developed in the Ontario district, while the segregation and pocket formations are more common in the Quebec district. A very characteristic section, showing the occurrence of pockets of apatite is given in Fig. 18. It is a figure from the side of McLaurin's mine in Templeton, Ottawa County, Quebec. The mineral seems to lie in no definite vein, but to have been formed by the segregation of apatite from the including rocks. This seems especially probable, as the surrounding pyroxene often contains 10 to 15 per cent. of apatite and seems to increase in richness as the pocket is approached. It is also well known that phosphate of lime has, more than any other mineral, the property of forming into concretionary and segregated masses. Thus Professor Rogers found, in the materials dredged in the Challenger expedition, numerous phosphatic concretions scattered over many parts of the sea bottoms. Again, in the phosphorite deposits of southwestern France and of Estremadura, in Spain, the concretionary form is one of the most common conditions of the phosphate, while in the phosphate region of South Carolina the nodular phosphates, especially those from Bull River, show sometimes a distinctly concretionary structure. At Crown Point, N. Y., phosphate of lime occurs in radiating and botryoidal masses forming the eupyrchroite of Emmons, and even in the guano beds of Peru concretionary nodules of phosphate of lime have been found.[1]

The pockets and fissures of apatite are of variable size (see Figs. 2, 14, 15, 16, 17, 18, and 21), sometimes being only a fraction of an inch in diameter and sometimes consisting of immense bodies of massive or crystalline apatite, measuring many feet in thickness. Such pockets are to be seen at the Emerald, Battle Lake, North Star, High Rock, Union, and other mines on the Du Lièvre River. The apatite is, generally, not sharply divided from the pyroxenite, but gradually blends with it. The pockets show sometimes a banded structure, such as that of a cavity lined with pyroxene and the central part occupied by apatite. Occasional large bowlders of country rock are found embedded in the

[1] In the introduction to this report yet other instances of concretionary forms are noted, as well as the fact that many are probably at present forming in the muds beneath certain swamps.—N. S. S.

apatite (see Fig. 12). Nearly all these pockets and fissure veins seem to take their distinctive characters from the including rocks. Thus where the including rock is pyroxenic, feldspathic, and calcareous, the crystals associated with the apatite are generally pyroxene, feldspar, and calcite; and where the country rock contains large amounts of hornblende, as at Bell's mine, Storrington, Frontenac County, at Barr's mine, and on Turner's Island in Clear Lake, in Renfrew County, Ontario, there are always found large quantities of this mineral in the vein matter. The few veins, however, in which the lines of separation from the country rock are sharply drawn, do not seem to be so dependent on the including rocks for their component minerals.

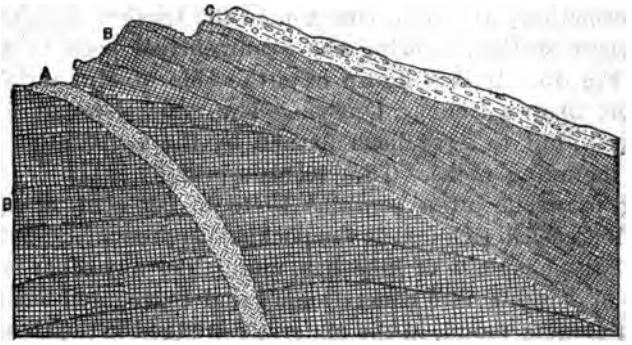


FIG. 20. Section in a pit near the Emerald mine, Buckingham, Ottawa County, Quebec, Canada. A, apatite; B, schistose pyroxene; C, drift. Scale: 1 inch = 6 feet.

The depth to which the apatite extends is probably, for all practical purposes, unlimited. Some bunches of the mineral run out, but others are found at a greater or less distance below. The deepest openings in Canada are the North Star mine, township of Portland, county of Ottawa, Quebec, and the Battle Lake mine, township of Templeton, of the same county. In September, 1886, they had reached the depths, respectively, of 350 feet and 210 feet. In both shafts large bunches of apatite were found, separated by pyroxenic or micaceous rocks containing smaller seams and bunches of that mineral.

The apatite of Canada varies considerably in its physical character. Its color is green, red, brown, white, blue, purple, or black. The black color is generally caused by the decomposition of the associated iron pyrites and is seen in Ottawa and Frontenac Counties. Apatite occurs in the crystalline, subcrystalline, massive, or granular form. The granular variety, known as "sugar apatite," is of a white or pale-green color and looks like coarse sand, more or less coherent. It occurs principally at the Little Rapids mine, township of Portland, and McLaurin's mines, township of Templeton, Ottawa County, Quebec, and is one of the purest forms of apatite mined. It is uncertain what could have

caused the apatite to assume this granular condition. Some shipments from Ottawa County have analyzed 88 per cent. of tribasic phosphate of lime. The apatite varies very much in its ability to withstand weathering. When it is free from pyrites it endures it very well and is almost as resistant to corrosion as quartz; but when pyrite is present it quickly crumbles away. In some places where pyrites of iron and copper are found the apatite is brown and rusty for a depth of several feet.

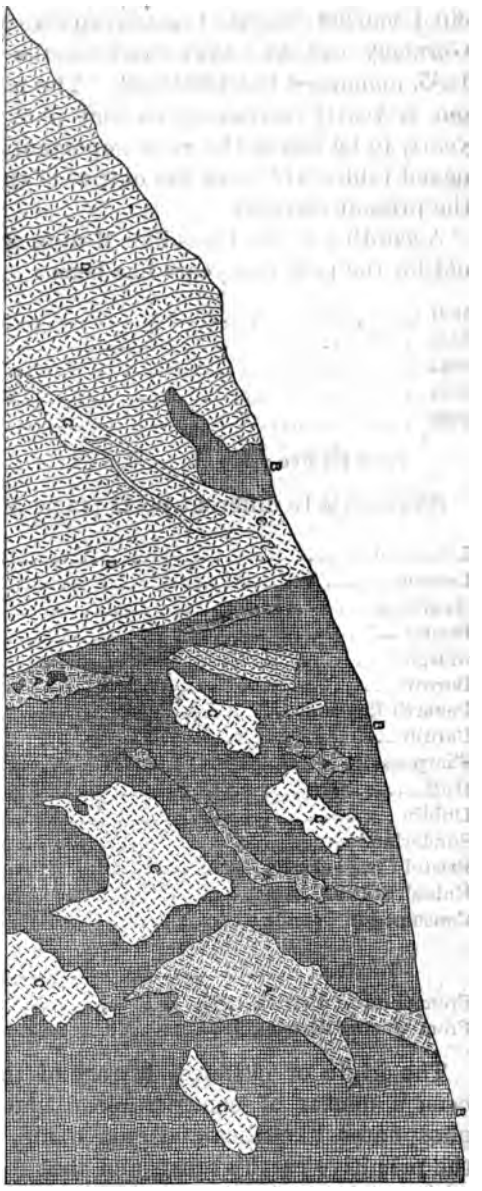


Fig. 21. North side of cut in west side of North Star hill, Portland East, Ottawa County, Quebec, Canada. A, apatite; B, pyroxene; C, feldspar; D, country gneiss, quartzite, and felsite. Scale: 1 inch = 25 feet.

Below is given a list of some of the more important minerals of the Canada apatite districts. The crystals often occur of immense size and in a state of great perfection. The zircons, sphenes, scapolites, pyroxenes, apatites, and micas are especially fine, and probably are found nowhere else in such quantities and in such perfection:

Apatite.	Opal.
Calcite.	Chalcedony.
Fluor-spar.	Albite.
Pyroxene.	Scapolite.
Hornblende.	Wilsonite.
Phlogopite.	Talc (steatite).
Garnet.	Chlorite.
Epidote.	Prehnite.
Idocrase.	Chabasite.
Tourmaline.	Galena.
Titanite.	Sphalerite.
Zircon.	Molybdenite.
Orthoclase.	Graphite.
Quartz.	

The apatite, after being blasted out, is put through the process of "cobbing," which consists in breaking it with a hammer from the adhering impurities.

The highest grade which is shipped rarely averages over 85 per cent. tribasic phosphate of lime, and none of the mines ship much phosphate which does not average at least 70 per cent. Eighty per cent. apatite is considered first quality and sells for 11 to 12 pence a unit.[1] The principal market for the Canada apatite is Europe. Great Britain and Germany consume over three-fourths of the total product, which, in 1885, amounted to 23,908 tons. The market is unlimited and the output is yearly increasing, so that phosphate mining bids fair, in a few years, to be one of the most important industries of Canada. The annexed tables will show the output of the mines in past years, as well as the present markets.

According to the Canadian Mining Review, January, 1886, the product for the past five years has been:

	Tons.
1881	15,601
1882	17,181
1883	17,840
1884	22,143
1885	23,908
Total for five years	96.673

Shipments to different ports (same authority):

	Tons, 1884.	Tons, 1885.
Liverpool	8,557	9,563
London	4,389	7,683
Hamburg	2,970	3,524
Bristol	1,824	2,056
Glasgow	3,083	482
Barrow	.....	350
Penarth Roads	100	100
Cardiff	.....	65
Sharpness	.....	45
Hull	.....	40
Dublin	210	.....
Sunderland	60	.....
Bristol Channel	50	.....
United States	200	.....
Consumed in Canada	700	.....
Total	22,143	23,908
From Ontario district, 1885		1,500
From Quebec district, 1885		22,408

The origin or chemical history of these Laurentian phosphates has been a matter of considerable dispute. Dr. T. S. Hunt says that phosphates, like silica and iron oxide, were doubtless constituents of the primitive earth's crust, and that the production of apatite crystals in granite veins or in crystalline schists is a process as independent

[1] The expression 11 to 12 pence a unit is the commercial method of signifying the value of the apatite. It means 11 to 12 pence for each per cent. Thus 80 per cent. *phosphate at 11 to 12* pence per unit would be worth $17.60 to $19.20 per ton

of life as the formation of crystals of quartz or of hematite.[1] Prof J. W. Dawson,[2] on the other hand, thinks the Canada apatites are of animal origin, and bases his belief on the presence of eozoön and of graphite in the associated beds and of the fluoride of lime in the apatite. He says: "The probability of the animal origin of the Laurentian apatite is, perhaps, further strengthened by the prevalence of animals with phosphatic crusts and skeletons in the primordial age, giving a presumption that, in the still earlier Laurentian, a similar preference for phosphatic matter may have existed, and, perhaps, may have extended to still lower forms of life, just as, in more modern times, the appropriation of phosphate of lime by the higher animals, for their bones, seems to have been accompanied by a diminution of its use in animals of lower grade."[3] Messrs. Brögger and Reusch,[4] in their description of the Norwegian apatites, think that they are of purely eruptive origin.

[1] Chem. and Geol. Essays, 1875, p. 311.

[2] Quart. Jour. Geol. Soc. London, vol. 32, 1876, p. 290.

[3] The reader should note the fact that since the admirable researches of Möbius it is doubtful whether eozoön be of organic origin.—N. S. S.

[4] Zeitschr. Deutsch. geol. Gesell., Berlin, vol. 27, 1875.

Table giving analyses of apatites of Canada by Christian Hoffman, Geological Survey of Canada, 1877–'78.

[I is from Storrington, province of Ontario ; II is from Buckingham, province of Quebec ; III is from North Burgess, province of Ontario ; IV is from Portland, province of Quebec; V is from Loughboro', province of Ontario : VI is from Portland, province of Quebec ; VII is from Buckingham, province of Quebec ; VIII is from Templeton, province of Quebec.]

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Phosphoric acid (1)	40.373	41.080	39.046	41.139	40.868	40.518	34.032	40.812
Fluorine (2)	3.311	3.474	3.791	3.863	3.781	3.377	2.855	3.554
Chlorine (3)	0.438	0.260	0.476	0.229	0.428	0.086	0.101	0.040
Carbonic acid (4)	0.026	0.370	0.096	0.223	0.105	0.855	2.848	0.518
Lime	47.828	49.161	46.327	49.335	48.475	49.041	44.198	49.162
Sulphur (5)							3.507	
Calcium	3.732	3.803	4.258	4.195	4.168	3.693	3.062	3.763
Magnesia	0.151	0.158	0.548	0.180	0.158	0.205	0.422	0.620
Alumina	0.609	0.705	1.190	0.566	0.835	0.267	1.979	0.565
Nickel, cobalt, and copper							Not det.	
Iron							5.370	
Sesquioxide of iron	0.151	0.125	1.290	0.094	0.905	0.083	0.120	0.125
Alkalis	?	?	?	?	?	?	?	?
Insoluble residue	3.890	0.370	3.490	0.060	1.150	1.630	2.050	0.630
Total	100.509	99.506	100.512	99.884	100.823	99.665	100.544	99.729
(1) Equal to tribasic phosphate of lime.	88.138	89.682	85.241	89.810	89.219	88.455	74.295	89.098
(2) Equal to fluoride of calcium	6.796	7.131	7.781	7.929	7.658	6.932	5.860	7.295
(3) Equal to chloride of calcium	0.685	0.406	0.744	0.358	0.669	0.134	0.158	0.062
(4) Equal to carbonate of lime	0.059	0.840	0.218	0.507	0.239	1.943	6.473	1.177
(5) Equal to pyrrhotite							8.877	

Analysis of apatite of Canada, by Dr. C. U. Shepard, jr.

	IX.
Phosphoric acid	39.80
(Equal to bone phosphate, 86.88.)	
Sand	5.91

APATITES OF NORWAY.

Under the heading of apatites come the phosphate deposits of Norway. They are found on the southern coast, and extend from Langesund Fjord to Arendal. They are also found scatteringly in Kongsberg, in the parish of Snarum. Most of them are fluor-apatites, though they all contain some chlorine, and the apatite from Snarum contains 2.71 per cent. of this element.[1] The apatite occurs in both the crystalline and the massive form, and varies from white and yellow to green

[1] A dark-blue or greenish-blue variety of crystalline apatite is found at Arendal, *and is known as moropite.*

or red. Some of it is the richest phosphate at present mined, averaging at times over 90 per cent. of phosphate of lime.[1] (See analyses, p. 45).

The mineral occurs in veins in the country gneisses, granites, quartzites, and schists, and also in a rock called by Brögger and Reusch spotted gabbro (gefleckter Gabbro), which is composed of brown hornblende and white or gray labradorite. It is generally supposed to be of eruptive origin. From its description it is very similar to the rock, including the apatite, at Bell's mine, Storrington, Ontario, described above, which is composed of green hornblendes and white feldspar, and occurs as an apparently eruptive mass in the country gneiss. The apatite seems to occur indifferently in this hornblende rock and in the other country rocks, though, wherever it has been discovered in the latter, the spotted gabbro is generally found in the neighborhood. The apatite is associated most commonly with micas, enstatite, hornblende, pyroxene, albite, tourmaline, copper and iron pyrites, and other minerals, including many other species of rarer occurrence which are hereafter enumerated. As in the Canadian deposits, the contents of the veins are variable, being in some places composed almost entirely of either mica or enstatite, or both, and in others consisting of apatite with only a few micaceous and pyroxenic impurities. The veins are markedly different from the Canada veins in the fact that they contain only very little carbonate of lime. The large calcareous veins containing apatite, which are so common in the Canadian apatite districts, are never found in the apatite districts of Norway. The apatite veins in Norway are often very numerous and run in all directions, forming a perfect network all through the rock. Thus at Oedegården there is an area of 58 square rods which is cut up by innumerable veins of all sizes. The principal one of these has been worked to a considerable extent; it dips at 45°, has a thickness of one foot to four feet, and a length of about five hundred yards. Dr. C. U. Shepard, jr., who visited it in 1874, says: "It was found in the face of a low, rocky ledge, occurring in mica and a clay slate."[2] The veins often show a banded structure, having the mica and hornblende on the outside and the apatite in the center, though in other places they also show, as is generally the case in Canada, a confused mass of crystallized minerals. At Regårdsheien there are five parallel veins, one of them one and a half feet thick and one hundred to one hundred and fifty feet long; four dip at 30°, while the fifth is almost vertical (Brögger and Reusch). At Krageröe there is a large vein seven feet wide. It occurs in granitoid and schist rocks, though from the summit of the hill, from which it crops out, there protrudes the eruptive gabbro. The vein matter is com-

[1] Some of the phosphate deposits of Norway, especially at Krageröe, partake very much of the nature of phosphorites, but they are all classed together here, as both varieties are so intimately associated that they cannot be conveniently separated.

[2] Dr. C. U. Shepard, jr., MS.

posed largely of hornblende and apatite in varying proportions, with crystals of rutile occasionally scattered through the mass. The hornblende often contains cavities lined with crystals of the same substance, and of quartz, apatite, and other minerals. At Nestesvåg the apatite vein occurs in quartzite. The minerals found in the Norway apatite are:[1]

Quartz.	Enstatite.
Apatite.	Phlogopite and green magnesian mica.
Calcite.	Chlorite.
Talc.	Aspasiolite.
Orthoclase.	Titanite.
Albite.	Hematite.
Oligoclase (and albite).	Rutile.
Esmarkite (anorthite ?).	Menaccanite.
Scapolite (and paleo-albite).	Magnetite.
Tourmaline.	Copper pyrite.
Hornblende.	Magnetic pyrite.
Pyroxene.	Iron pyrite.

The apatite of Norway was mined as early as 1854. The first deposits worked were those of Krageröe, from which, between the years 1854 and 1858, 13,000 tons were taken and sold for $110,000. The Oedegården deposits were discovered in 1874 by Axel Esmark, a Norwegian mineralogist. They have since been worked on a small scale. The difficulty of mining Norwegian apatite has been so great, however, that the yearly output has never exceeded a few thousand tons, and the mineral at present has been almost driven out of the market by the Canada, Curaçoa, and other high-grade phosphates.

As regards the origin of the Norwegian apatites, Brögger and Reusch think they are of eruptive origin. The banded structure of the veins they ascribe to the way the minerals solidified from a state of fusion. The country rocks are almost absolutely destitute of phosphoric acid in any form, and, consequently, they infer that the vein matter is in no way dependent on the surrounding rocks. Another argument which they bring up in support of the eruptive theory is that veins are often seen to be fine-grained on the outside and coarse and crystalline in the center.

Table giving analyses of apatite of Norway, by Dehern.

	Yellowish brown.	Brown.	Black.	General sample.	Poor quality.
Phosphoric acid	34.82	33.25	26.25	34.88	17.56
Equivalent to bone phosphate	76.01	72.58	57.30	76.14	38.33
Sand	7.07	7.81	21.01	4.95	35.89

[1] Zeitschr. Deutsch. geol. Gesell., vol. 27, 1875, pp. 672, 673.

Table giving analyses of high-grade Norwegian apatite, by Dr. C. U. Shepard, jr.

	I.	II.
Phosphoric acid	38.79	37.66
Equivalent to bone phosphate	83.68	82.21
Insoluble siliceous matter	8.13	7.39

Analysis of apatite from Arendal, Norway, by G. Rose.

Phosphoric acid (1)	42.229
Fluorine (2)	3.415
Chlorine (3)	0.512
Lime	49.960
Calcium	3.884
	100.000
(1) Equal to tribasic phosphate of lime	92.159
(2) Equal to fluoride of calcium	7.010
(3) Equal to chloride of calcium	0.501

APATITES OF SPAIN.

The only other apatite deposits which have yet become of commercial importance are in Spain. At Malpartida de Cáceres are the mines of Señor Grappin. The mineral occurs in granite, and about six thousand tons annually have been shipped in good years. Considerable deposits of apatite are found at Zarza la Mayor, and at Ceclavin, in the district of Alcantara, near the Portuguese frontier, and about twenty miles from the Tagus. Crystalline apatite is also found in the volcanic rocks at Jumilla, in the province of Murcia, which averages 86 per cent. phosphate of lime.[1] It is also found in the provinces of Alemtejo and Zamora.[2] The Jumilla apatite is often of the yellowish-green variety, known as asparagus stone or Spargelstein.

The Spanish apatite deposits are limited in quantity, compared with the phosphorite deposits of that country, and they have never produced more than a very few thousand tons annually. At present, on account of the disturbed political condition of the country, no apatite is exported.

A description of the other Spanish deposits is given under the subject of phosphorites.

Analyses of Spanish apatite.

I. Apatite from Zarza la Mayor, by Dr. C. U. Shepard, jr. Mas[illegible]

Tribasic phosphate of lime	77.14
Sand	7.49

[1] O. Ramon T. Muñoz de Luna: Estudios químicos sobre los abonos minerales en general, y particularmente sobre la importancia de los [illegible] Madrid, 1875.

[2] Naranjo y Garza en Luna: Prof[illegible] ... [illegible] pág. [illegible] y 227.

[II. Apatite from Murcia, by G. Rose.]

Phosphoric acid (1)	42.172
Fluorine (2)	3.434
Chlorine (3)	0.566
Lime	49.894
Calcium	3.934
	100.000
(1) Equal to tribasic phosphate of lime	92.066
(2) Equal to fluoride of calcium	7.049
(3) Equal to chloride of calcium	0.885

PHOSPHORITES.

"The name phosphorite was used by Kirwan for all apatite, but in his mind it especially included the fibrous, concretionary, and partly scaly mineral from Estremadura, Spain, and elsewhere."[1] In this latter sense it is used here, but it will also include certain vitreous and earthy forms which are often so intimately associated with the above-mentioned varieties and which often run into them by such gradations that they are best described together.

The phosphatic deposits of Nassau, in Germany; those of the southwest of France, commercially known as "Bordeaux phosphates," and those of Estremadura and Cáceres, in Spain, come under this head.

PHOSPHORITES OF NASSAU.

The phosphorite deposits of Nassau were discovered in 1864 by Herr Victor Meyer, of Limburg, though as early as 1850 Dr. Sandberger had discovered apatite in the manganese mines of Kleinfeld.

The principal phosphorite deposits occupy an irregular area, bounded on the northeast by the town of Weilburg, on the northwest by the Westerwald, on the east by the Taunus Mountains, and on the south by the town of Dietz. The general appearance of the country is that of a broad plain, intersected by the Lahn and its tributaries. The phosphorite is found in cavities in a hard, massive, dolomitic limestone of the Devonian age. The following section,[2] in an ascending order, will show the geologic relations of the deposits:

(1) Porphyry, dark to light gray and green, containing cavities of calcareous matter.

(2) Slaty and shaly beds, much contorted.

(3) Dark-red sandstone, containing beds of hematite.

(4) Dolomitic limestone, white, blue, or pink in color, resting unconformably on the underlying bed.

(5) Phosphorite deposits.

(6) Brown clay, supposed to be Tertiary.

The phosphorite is sometimes found on the surface and sometimes under as much as two hundred feet of clay. The hollows containing the phosphorite are generally much worn and have all their edges rounded off, as if they had been exposed to the action of water for a long time before the phosphorite was deposited in them (Figs. 22, 23).

[1] J. D. Dana: A System of Mineralogy, 1873, p. 531.

[2] *D. C. Davies:* Geol. Mag., vol. 5, London, 1868, p. 262.

The phosphatic deposits vary from six inches to six feet in thickness and seem to attain their greatest continuity in a belt running in a northeast and southwest direction, thinning out gradually at both extremities. They seem to occur only with the limestone, and are no longer found when that rock disappears. This would seem to indicate that they depend on the limestone for their origin.

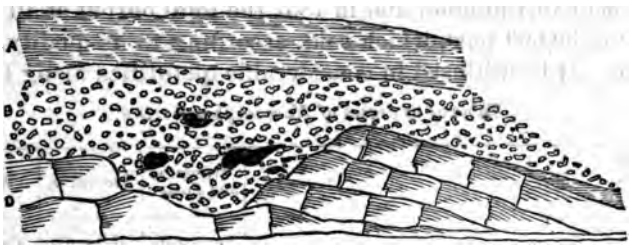


FIG. 22. Section at Cubach, Nassau, Prussia. After D. C. Davies: Geological Magazine, London, 1868. A, clay; B, phosphate of lime; C, manganese; D, dolomite.

The phosphorite is found in a great variety of forms. It is generally massive, fibrous, earthy, porous, jasper-like, kidney-shaped, stalactitic, or nodular. Occasionally there are found in it minute crystals of apatite (Davies). Sometimes, also, it occurs as an incrustation, and it is then known as staffelite, from its abundance near the town of Staffel.

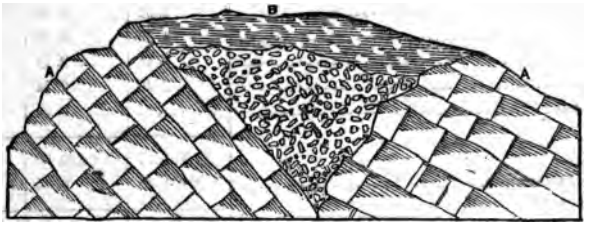


FIG. 23. Section at Staffel, Nassau, Prussia. After D. C. Davies: Geological Magazine, London, 1868. A, dolomite; B, clay; C, phosphate of lime.

This mineral is, generally, white, yellow, green, or brown in color, and occasionally translucent. The other varieties are of almost all colors, white, yellow, red, gray, blue, green, brown, or black. Occasionally a brecciated variety is found, but the larger part of the deposit is of the massive kind.[1] The hardness varies from 1 to 5. With the phosphorite occasionally occur deposits of crystalline hematite and manganese ore. These minerals are most common on the outside edges of the phosphate-bearing area, but are also found with it in the same deposit. The amount of phosphate of lime in the phosphorite is very variable, averaging from 60 to 92 per cent. (see analyses). It is generally richest when associated with the least hematite and manganese and, when free from the former mineral, it makes an excellent superphosphate. Among the other minerals associated with this deposit are wavellite, calcite, quartz, wollastonite, jasper, and chalcedony.

[1] Dr. C. U. Shepard, jr., MS.

There are no signs of organic remains in the Nassau phosphorites, but they are generally believed to be of animal origin. Dr. Mohr thinks they were formed by the concentration of the phosphate of lime from the underlying limestones. At present not much phosphorite is exported on account of the difficulty of freeing it from the associated iron and the expense of mining it. Several years ago, however, large quantities were sent to England, and in 1867 the total output of all the mines amounted to 30,000 tons, which sold, according to its quality, for $5 to $8 per ton. It is still used in considerable quantities along the Rhine.

Table of analyses of Nassau phosphorites.

	Fresenius and Foster.	Fresenius.	Wicke.
	Pure staffelite.	General sample.	General sample.
Lime	45.79	47.31	42.31
Magnesia	0.16	0.12	0.23
Sesquioxide of iron	6.42	3.77	8.22
Alumina	1.08	1.67	2.23
Potash	0.58	0.66	1.26
Soda	0.42	0.52	0.09
Phosphoric acid	34.48	33.84	30.63
Carbonic acid	1.51	2.75	2.78
Silicic acid	4.83	5.04	6.61
Fluorine	3.45	2.11	3.74
Water	2.45	2,74	3.00
Sulphuric acid	.....	.....	1.07
	101.17	100.53	102.17
Deduction for oxygen	1.45	0.84	1.57
	99.72	99.69	100.60

PHOSPHORITES OF SOUTHWESTERN FRANCE.

The phosphorites of the southwest of France are in the departments of Lot, Tarn-et-Garonne, and Aveyron. The region is limited by the valleys of the rivers Lère, Cellé, and Aveyron, and the phosphorite is found in largest quantities near Caylus and at St. Antonin, Limogne, Cajarc, Figeac, Villeneuve, Bozouls, and other places on the southwestern side of the central plateau. The material occurs in fissures and cavities in the surfaces of hard, compact, gray limestone plateaus which belong to the Oxfordo-Coralline group of the Jurassic formation. The deposits are of two kinds.[1] The first occurs in irregular cavities, never over a few yards long, and partaking more or less of the character of pockets; the second, in the form of elongated leads, with sides which are nearly vertical and which run in a generally parallel direction, widening and narrowing at intervals. They are generally shallow and

[1] Mr. Daubrée: Comptes rendus Acad. sci., Paris, vol. 73, 1871.

thin out very rapidly at a short distance from the surface. They often, however, continue for some distance longitudinally. Thus, at Pendaré, the surface of the phosphate lead is three to ten yards wide and has been followed in a straight line for 100 yards. Any sudden turn or curve in the fissure is, according to Mr. Rey-Lescure,[1] almost sure to make the lead thin and poor. The richest leads are those which run in a straight line and have walls which are smooth and tend toward a vertical position. According to Mr. Daubrée,[2] the fissures seem to follow certain definite directions. Thus, at Pendaré and Mas-Merlin, they run ENE. and WSW. At the same time there is another series of leads running at right angles to these. The phosphatic material of the leads running in different directions is of very different character, as will be hereafter shown.

The phosphorite occurs in a great number of forms. Sometimes it has a rounded, concentric, and radiated structure; at others it occurs in nodular and mammillated masses. Often it is found in agate-like zones, forming twenty to thirty layers in a thickness of a centimeter. Sometimes it occurs as geodes,[3] and at other times it is found in fibrous masses, very much resembling aragonite. The phosphorite varies very much in hardness, compactness, and general appearance. The purest form is as hard as apatite, has a resinous or subvitreous luster and a yellowish-brown color. Sometimes the color is of a light blue, possibly due to the presence of phosphate of iron. The impure varieties are white, yellow, or red, and are often soft and earthy. The phosphorite which occurs in the form of nodules is often hollow in the interior, containing loose stones in the cavities (Daubrée). The whole mass is mixed with siliceous pebbles, clay (more or less ferruginous), loose blocks of calcareous rock, and pisolites of iron, all solidified into a mass varying very much in compactness and generally containing numerous cracks and cavities. Often pyrolusite is associated with the phosphorite, occurring in thin layers or in the form of dendrites. The presence of iodides has been detected, in which respect it resembles the phosphorite of Amberg in Bavaria. Minute quantities of bromides are also found. The presence of pisolites of iron is most frequent near beds of iron ore; and the iron, according to Rey-Lescure,[4] probably has been derived from such beds.

Mr. Trutat has found that in the leads which run ENE. and WSW. the phosphorite is compact, vitreous, agate-like, and, rarely, geodic. In the leads at right angles to these the mass of phosphatic material consists apparently of geodes filled with carbonate of lime or ferruginous clay. The geodes are, however, generally broken and in fragments, so that their contents cannot be observed. The leads of the first variety

[1] Bull. Soc. géologique France, 3d series, vol. 3, 1875, p. 398.

[2] Comptes rendus Acad. sci., Paris, vol. 73, 1871.

[3] Mr. Leymerie: Note sur les phosphorites du Quercy, Toulouse, 1872.

[4] Bull. Soc. géologique France, 3d series, vol. 3, 1875.

generally consist of long fissures with parallel walls, while those of the second variety represent the irregular pockets described by Daubrée. Trutat thinks that the ENE. and WSW. leads were formed first, and that those at right angles to them were formed later, by the action of carbonic acid, which dissolved part of the original leads and redeposited it in new hollows and crevices.

The phosphorite deposits are usually capped by a deposit of ferruginous clay, containing pisolites of iron, bones of land animals, and numerous land and fresh-water shells. Among the bones are the remains of many carnivorous, herbivorous, and omnivorous animals, all mixed together. The bones are well preserved and not affected by chemical action. The deposits of Cregols and Beduer have afforded immense quantities of bones of carnivorous animals, and in the deposits of Raynal, Servanac, and Mouillac are found the remains of many skeletons of anthracotherium, palæotherium, and rhinoceros of several varieties. The bones are also occasionally found embedded in the phosphatic matter itself.[1] Thus, near La Mandine there are so many remains of palæotherium (*P. medium*) that from one cubic decimeter of phosphatized marl four or five fragments of different jawbones and many other bones were obtained. Remains of hyænodon and many land and fresh water mollusks, among them *Planorbis* and *Limnæa*, as well as turtle remains, are found in many deposits. Bones of cainotherium and anoplotherium are of frequent occurrence. Though the rock which contains the phosphorite deposits is of Jurassic age, the phosphate itself is generally believed to be of early Tertiary (Eocene) age. The way in which the phosphorite came to occupy its present position, however, has been a much more disputed point than the time in which the deposit was formed. Daubrée,[2] Rey-Lescure,[3] Leymerie,[4] and others are of the opinion that the phosphate came from mineral springs, rising from the bottom of the fissures. The phosphate was dissolved by the action of hot water containing carbonic acid, and, when it came into the fissures, the carbonic acid was lost and the phosphate was deposited. They think the bones are too few to have anything to do with the origin of the phosphate.

Filhol[5] urges against this theory that in all the deposits which have been worked out, and thus afforded a chance of examining the sides of the crevasse, he has found that the phosphate does not run into other leads by narrow necks and veins, as Rey-Lescure asserts, but that the leads are in no way connected with each other and that the crevices show no openings through the limestone which could have served as an exit for the phosphatic solution. Consequently he concludes that

[1] Mr. Daubrée: Comptes rendus Acad. sci., Paris, vol. 73, 1871.

[2] Alph. Peron: Bull. Soc. géologique France, 3d series, vol. 2, 1874.

[3] Bull. Soc. géologique France, 3d series, vol. 3, 1875.

[4] Note sur les phosphorites du Quercy, Toulouse, 1872.

[5] Annales sci. géol., vol. 7, 1876; Recherches sur les phosphorites du Quercy, pp. 1–220.

the deposits were formed by a solution of phosphate of lime in carbonic acid, running from the surface downward into the fissure. When all the fissures were filled the solution often spent its strength in phosphatizing the marl of the neighborhood. Thus at La Mandine Basse they find a calcareous marl containing 25 to 30 per cent. phosphate of lime.

Mr. Combes[1] thinks the phosphate bed was formed by phosphatic vapors rising up through the Jurassic limestone and phosphatizing it. He thinks a similar action is going on at the present time. Mr. Malinowski[2] thinks that the beds are of purely animal origin and that volcanic eruptions of Auvergne killed all the animals of the period and thus furnished the phosphate to fill up the fissures. Mr. Delfortrie[3] thinks the deposit is of Quaternary age and derived from altered guano.

Mr. Peron[4] has shown that the phosphate deposits only occur where the Tertiary deposit now exists or where it has existed in time past. Thus on the Jurassic plateau at Bach, Mouillac, and Malpérie, the Tertiary formation which covers it at Lavaurette, Monpalach, and Lasalle, in Tarn-et-Garonne, has been eroded. Yet both districts are rich in phosphate. On the other hand, at Laussiers and Anglars, where he supposes the Tertiary has never existed, there is no phosphate. He thinks the phosphate deposits are synchronous with the Lower Tertiary of Aude and Tarn. The waters of the Eocene, he supposes, came suddenly over the Jurassic plateau, overwhelming the numerous land animals of the region and sweeping the remains of these and masses of guano into crevices and cavities, together with quartz pebbles, land and fresh-water shells, and other débris. Then the action of time and carbonated waters partially metamorphosed the phosphate and converted it into concretions and other forms of phosphorite in the midst of the clay and bones. At a later time the superficial deposits of bones were laid down.

The strongest arguments of the advocates of the hydrothermic theory are the presence in the phosphorite deposits of iodine and manganese, and of pisolites of iron, which are generally of hot spring origin.

Peron thinks these latter were formed during the deposition of the Lower Tertiary formation. He also calls attention to the fact that phosphorite has nowhere been found in the southwest of France at a greater height above the sea than 320 meters. This he explains by supposing that the waters of the early Tertiary did not extend above this height.

The phosphorites of the southwest of France were discovered in 1865, on the plateau of Quercy, in the department of Lot, by Mr. André Pouмarède. Five years later the deposits of Lot-et-Garonne, Tarn-et-Garonne, and Aveyron were discovered and worked until the last few years,

[1] Phosphorites du Quercy, Revue scientifique, 1872, No. 12.

[2] Traité spécial des phosphates de chaux natifs, Cahors, 1873.

[3] Les gîtes de chaux phosphatée dans le départ. du Lot, Bordeaux, 1873.

[4] Bull. Soc. géologique France, 2d series, vol. 2, 1874.

when the exports ceased. The best deposits had given out and the others contained so much iron and alumina that the material was very undesirable as a source of superphosphate. For several years, from 1870 to 1875, an average of 20,000 tons per annum was exported.[1] Some of the mines are still worked, but the phosphate is used only in a raw state and for local purposes.

Soon after mining had begun in this region, Guillier estimated that the total contents of all the mines would not exceed 100,000 tons. This estimate was much too small, but it serves to show that the deposit is a very limited one. The phosphate was formerly collected in loose bowlders from the fields for the purpose of building walls. At the Pearl mine, near Cajarc, the phosphorite crops out at the surface.[1] At the depth of 75 feet the lead becomes very thin and uncertain. The mass of the phosphorite is, in some places, 10 feet thick, but ordinarily it consists of several more or less parallel bands, which end abruptly.

One of the largest mines is at Larnagol, in the department of Lot. It is situated on the summit of an Oxfordian plateau over a thousand feet high. The first quality rock is cleaned by hammer and hand, and the second quality in a simple horizontal washer, driven by steam. The phosphorite contains both chlorine and fluorine, but in much smaller quantities than exist in apatite. As has been said before, it also contains iodine, and in some specimens traces of bromine have been detected.

Table of analyses of phosphorites from southwestern France.

[I. Analyses by Bobierre.]

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Siliceous sand	1.00	4.70	12.70	12.06	3.00	1.00	1.40	0.93
Phosphoric acid	38.00	32.94	36.48	35.84	36.80	37.10	37.00	38.32
Total lime	51.47	.....	.....	.....	.....	.....	51.50	48.92
Water volatilized at red heat, fluorine, chlorine, carbonic acid, and oxides of iron and manganese	9.53	.....	.....	.....	.....	.....	10.10	11.83
	100.00	.....	.....	.....	.....	.....	100.00	100.00
Lime in excess of phosphoric acid, and combined with carbonic acid, fluorine, and chlorine	6.87	.....	.....	.....	.....	.....	8.10	3.94

[1] Dr. C. U. Shepard, jr., MS.

Table of analyses of phosphorites from southwestern France—Continued.

[II. Analyses by C. U. Shepard, jr.]

	High-grade phosphorite, from Mas-Merlin.	Low-grade phosphorite, from Larnagol.
Phosphoric acid	38.64	21.46
Equal bone phosphate	84.35	46.85
Sand	1.00	14.58

Superphosphates made from 12 parts (by weight) of rock and 9 parts of sulphuric acid (1.50 specific gravity) gave:

High grade ..... 14.98 per cent. soluble phosphoric acid.
Low grade ..... 5.04 per cent. soluble phosphoric acid.

[III. Analyses of commercial Bordeaux phosphate by C. U. Shepard, jr.]

	I.	II.
Phosphoric acid	35.46	34.45
Equal bone phosphate	77.41	75.20
Sand	4.35	8.55

Superphosphates made in the same way as the last case gave:

	I.	
Soluble phosphoric acid	15.00	12.48

PHOSPHORITES OF SPAIN.

The phosphorite deposits of Spain are situated near the towns of Logrosan and Cáceres, in Estremadura. The two localities differ somewhat in the mode of occurrence of the phosphorite as well as in its physical properties, and will therefore be treated separately.

Logrosan deposits.—The country in which these occur is a broad tableland composed of a clay slate and studded here and there with conical peaks rising abruptly from the level of the plain, and often reaching the height of three hundred to six hundred feet above the surrounding surface. There also occur numerous long, flat ridges, rising, like the peaks, abruptly from the surface of the plateau. The slate is of very variable character, being composed sometimes of a dark-blue, fissile schist, sometimes of a micaceous or a talcose schist, and at other times of alternating beds of talc and feldspar.[1] No fossils are found in this formation, but in a very similar deposit near Almaden, and about eighty miles from the town of Logrosan, are found numerous fossils,

[1] Charles Daubeny and Captain Widdrington: Jour. Roy. Agric. Soc., 1845.

such as *Spirifer attenuatus* and trilobites. Consequently the slate formation of Logrosan and Cáceres has been referred by some French and Spanish geologists to the Silurian formation. Le Play[1] refers it to an older formation than the fossiliferous slates of the neighborhood of Almaden. The conical peaks rising up from this formation are granitic intrusions. They are very feldspathic and often much weathered. In this latter respect they differ from the long, flat ridges spoken of above. These are beds of quartzite interstratified with the country rock, which has a quite regular, almost vertical dip. The quartzite is sometimes very compact and homogeneous and at others it is granular and often resembles a sandstone. It has resisted the erosive action, which has worn down the more easily attacked parts of the slate formation and now stands out in bold, angular ridges. The section (Fig. 24) from Truxillo to Logrosan, a distance of seven Spanish leagues, will show the general character of the country. Besides the rocks already mentioned, large veins of dark limestone are occasionally found cutting through the slate formations.

FIG. 24. Section from Truxillo to Logrosan, Spain, after Daubeny and Widdrington. A, granite; B, slate; C, phosphorite.

The phosphorite occurs in true veins and in pockets. Occasionally it occurs as a vein at the line of junction of the granite with the country slate. It is of a variable character, occurring sometimes in an amorphous and compact form, at others in a fibrous or concretionary state, often inclosing pebbles of white or ferruginous quartz. It varies in color from white and yellow to a rich, jasper-like red. It is often covered with dendrites of manganese, and occasionally agate-like varieties are found in which the phosphate is interstratified with bands of lilac amethyst. The palmated variety is generally the purest and the most abundant. It has a hardness of 5.5, and a specific gravity of 3.12. When heated in a darkened room it gives off a bright phosphorescent light.[2]

At Logrosan there are six principal deposits of phosphorite. They are known as Costanaza, Jungal, Castillon, Angustias, Terrenos Colorados, and La Cambre Bojera. The Costanaza vein is by far the largest phosphorite vein known in all Spain, and perhaps in the world (Shepard).[3] It extends for about two and a half miles from the foot of Mt. Boyales, on the north, in a southeasterly direction past Mt. Cristobal. The vein dips at an angle of 60° to 90° toward the east (Garza and

[1] Annales des mines, 1836.

[2] Sur la phosphorite de Logrosan, Estremadura, Messrs. Naranjo y Garza and Lino Peñuelas: Bull. Soc. géologique France, 1860, vol. 17, p. 157.

[3] *Foreign Phosphates*, 1879, p. 25.

Peñuelas), and cuts obliquely through the country slate, which has a strike of north 15° to 45° east, and a dip of 70° southwest. The vein has been worked principally where it crosses hills, and especially near the chapel of Nuestra Señora del Consuelo. It varies from ten to twenty feet in width and contains streaks of quartz and horses of country rock. The walls of the slate show signs of considerable decomposition and disintegration. The vein thins out at each end, and also grows narrow at a depth; though, as the excavation is only about forty feet deep, the bottom has not yet been reached.[1]

The second vein, Jungal, is at the entrance of the town of Logrosan, on the road to Truxillo. It has a mean width of 32 inches and a length of one thousand to twelve hundred feet. In most respects it resembles the Costenaza vein, but is on a much smaller scale.

The Castillon vein runs under the town for a considerable distance and varies in width from five to six and three-fourths feet. It presents a mass of phosphorite of great purity.

The Angustias lead is on the side of the hill Nuestra Señora del Consuelo and runs towards Mt. Boyales. It is not so valuable as some of the other leads, because of being much cut up by quartz veins and horses of country rock.

The Terrenos Colorados vein is 330 feet long and averages six and two-thirds feet wide. It is parallel to the Cambre Bojera lead, which is about the same size.

The general direction of all these veins is northwest and southeast, with a dip of 60° to 90°.

The Logrosan phosphate has a subcrystalline structure; some specimens are fibrous and radiating and often resemble feathers. It is soft and chalky to the touch, easily broken, but difficult to grind into a fine powder. An examination under the microscope exhibits conchoidal figures interrupted with spherical grains, devoid of color and opaque (Shepard). It is infusible before the blowpipe; but, on being subjected to long-continued heat, a luminous disk, perceptible in the dark, makes its appearance at the point of contact of the mineral and flame, and a green phosphorescence appears when it is heated for a short time. It is readily soluble in hydrochloric, nitric, or sulphuric acid.

The highest-grade material is rosy white or yellowish white in color, soft, concentric, often brilliantly radiated, with a mamillary or conchoidal surface. Red spots from iron and beautiful dendrites of manganese are not infrequent. The poorer qualities are milky white, vitreous, hard, and, though free from limestone, contain considerable silica.

The shipment of phosphate from Logrosan involves great trouble and expense. The mineral is drawn by ox or mule teams to the nearest railroad, a distance of 30 miles, and is shipped at Villanueva de la Serena. This carriage costs about 20 cents per cwt., and the carts make two

[1] Dr. C. U. Shepard, jr., MS.

trips a week, carrying 40 to 50 cwt. each trip. This, with the expense of getting it to Lisbon and thence to England, makes it cost about $15 a ton to land in London. First-class phosphorite (80 to 85 per cent.) sold there, in 1875, for $25 a ton.

In the Cáceres district, which supplies most of the phosphorite shipped from Spain, the mode of its occurrence differs from that in the Logrosan district. While in the latter it occurs in veins, sometimes of considerable length, at Cáceres it occurs in pockets in great veins of quartz and dark limestone, which are found cutting through the country slate. The principal mines are united in the Fraterjidad Company, and are known as the Esmeralda, Estrella, San Eugenio, Abundancia, Cacereña, San Salvador, and La Perla.[1] The first four, being the only mines of much importance, will alone be described. As will be seen from the ground plan (Fig. 25), the limestone and quartz veins, in which the phosphate is found, occur in both the granite and the slate rocks.

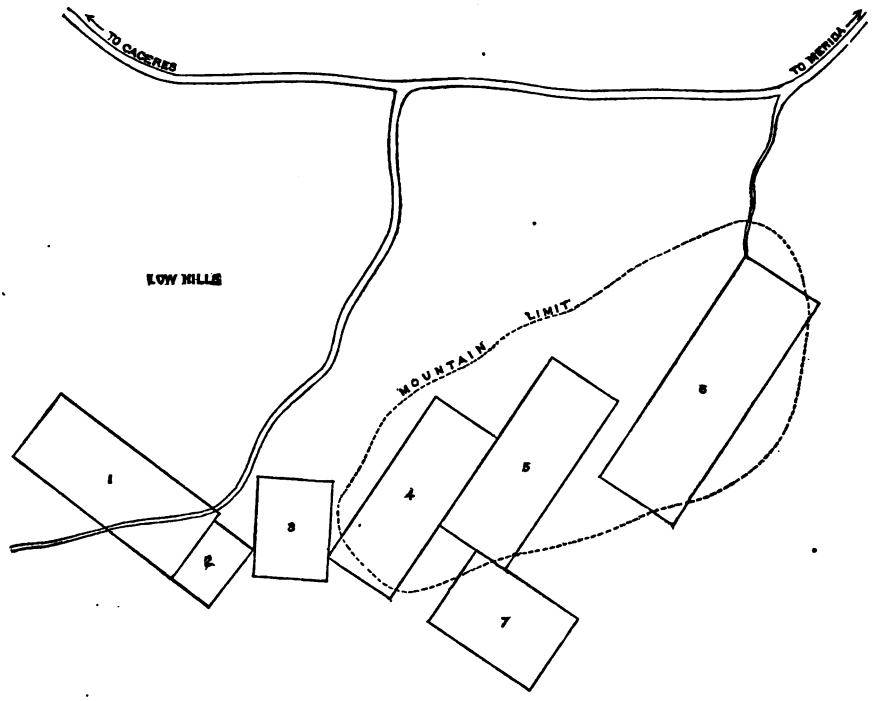


FIG. 25. Ground plan of the Cáceres mines in 1875; after Dr. C. U. Shepard, jr. (MS.). 1, Abundancia mine; 2, Carcereña mine; 3, San Eugenio mine; 4, San Salvador mine; 5, Estrella mine; 6, Esmeralda mine; 7, La Perla mine.

The Esmeralda mine is considered the largest and best of the Cáceres mines. There are two veins penetrating the side of a hill in a north

[1] C. U. Shepard, jr., MS.

and east direction, respectively, at an angle of about 45°. The vein to the north has a thickness of ten to twenty feet, and contains a variable quantity of limestone and siliceous rock. The immediately surrounding rock is limestone of a hard, brown character, which has been excavated for a depth of some one hundred feet (1875). The leads appear to narrow as they are followed into the hill. The exterior of the mass of phosphate is hard, white, and compact, while toward the center it becomes soft, crumbly, and of a rosy color (Shepard). There is less hard, siliceous rock here than in the other mines.

At the Estrella mine the lead enters the hill in which the Esmeralda mine is situated at an angle of 45°. The total thickness of the deposit is ten to twenty feet. It is very irregular in shape and grows thinner as it enters the hill. It contains less of the rich, pulverulent variety of phosphorite and more of the compact, vitreous variety than the last mine. Like the Esmeralda mine, it is in a limestone vein (Fig. 26).

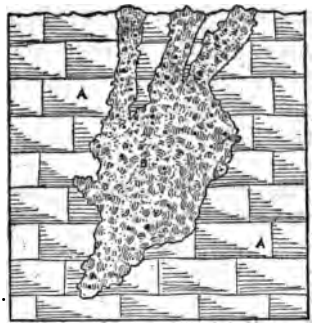


FIG. 26. The Estrella deposit in Estremadura, Spain; after C. U. Shepard, jr. (MS.). A, limestone; B, phosphorite.

The San Eugenio mine is smaller than either the Esmeralda or the Estrella. The lead is almost vertical and the phosphorite in some places is of a very high grade, but in others it is very siliceous and impure.

The Abundancia mine has been abandoned on account of the trouble from water. It is simply a round open pit 75 feet deep and 100 feet in diameter. It once gave large quantities of excellent phosphorite, but what is now left is siliceous and contains only 50 to 65 per cent. phosphate of lime, while the best Spanish phosphate will average 80 to 85 per cent. (See analyses pp. 58, 59.) The Cáceres phosphate is massive and amorphous and of two varieties: (1) Somewhat granular, easily crumpled, and of a white or rosy color; (2) dense, vitreous, hard, and white, with occasional streaks of quartz or limestone.

Cáceres is 43 miles north of Merida, a station on the railroad between Madrid and Lisbon, and near the Portuguese frontier. The cost of transportation between the two places varies from 12½ to 20 cents per cwt. Thence to Lisbon costs $4.55 per ton, making the total cost to Lisbon amount to $5 to $8 per ton. The Cáceres mines were not opened

until 1860, and from that time until 1875 the mines had exported only 124,156 tons of phosphorite.

The Logrosan deposits were the first phosphorites found in Spain. The earliest mention of them is by William Bowles in 1782.[1] He says that at the base of the Guadalupe Mountains, and near the town called Logrosan, the royal road is traversed by a vein of phosphoric stone, running in a north and south direction. It was also mentioned by La Play, Proust, and others in the early part of this century. But the deposit did not attract much attention until Professor Daubeny, of Oxford, and Captain Widdrington[2] visited the Logrosan country in 1844 and made a thorough study of the one vein then known. Later, in 1849, Mr. Naranjo y Garza, by order of the Spanish government, made a survey of the basin of the Guadiana and gave a description of the Logrosan phosphate deposits.[3]

The Cáceres deposits were discovered in 1860 by Mr. R. De Luna.

Ever since about 1855 the Spanish phosphorites have been worked at intervals. The phosphorite is of excellent quality, commands a high price, and makes as good a superphosphate as any phosphate known. But the expenses of transportation and the occasionally unsettled political condition of the country have been great detriments to the development of the mines.

Analyses of phosphorites of Spain.

[I. Logrosan phosphate, by De Luna.]

Water	0.40
Bone phosphate of lime	82.10
Phosphate of iron	5.20
Phosphate of magnesia	0.30
Fluoride of lime	7.31
Carbonate of lime	1.74
Chloride of lime	0.40
Silica	2.55
	100.00

[II. Logrosan phosphorite, by Professor Daubeny.]

Silica	1.70
Protoxide of iron	3.15
Fluoride of lime	14.00
Phosphate of lime	81.15

[III. Logrosan phosphate, by Messrs. Pelletier and Donadei.]

Phosphoric acid	40.12
Silica and clay	3.10
Hydrochloric acid	0.06
Hydrofluoric acid	2.27
Lime	53.50
Peroxide of iron	0.61
Loss	0.79

[1] Natural History and Physical Geography of Spain, Madrid, 1782.

[2] Quart. Jour. Geol. Soc. London, vol. 1, 1845, pp. 52–55.

[3] *La Gazette* de Madrid, July 22, 1849. Revista Minerva (March and July, 1855).

[IV to VII. Logrosan phosphate, by Dr. C. U. Shepard, jr., and Dr. Wamer.]

	IV. White and hard.	V. Yellowish white and hard.	VI. Rosy white and compact.	VII. White, soft, and mammillary.
Phosphoric acid	36.97	37.55	42.17	41.72
Equal bone phosphate	80.71	82.97	92.06	91.09
Sand and insoluble matter	12.63	7.40	Trace	4.32

[VIII to XIV. Cáceres phosphate, by Dr. C. U. Shepard, jr., and Dr. Wamer.]

	VIII. Rosy and pulverulent.	IX. White and hard.	X. Rosy and pulveruleat.	XI. White and hard.	XII. San Eugenio.	XIII. Abundancia.	XIV. Mina Rosa, at Malpartida de Cáceres.
Phosphoric acid	37.38	32.06	38.07	29.09	39.07	27.00	36.18
Equal bone phosphate	81.60	69.99	83.11	63.50	85.29	58.94	78.98
Sand	3.40	22.97	6.30	2.70	9.19	3.76	Trace

[XV. Cáceres phosphate, by Bobierre and Friedel.]

Insoluble siliceous matter	21.05
Water expelled at red heat	3.00
Tribasic phosphate of lime	72.10
Loss, oxide of iron, etc	3.85
	100.00

[XVI. Phosphate from Montanchez, by Bobierre and Friedel.]

Tribasic phosphate of lime	85.03
Carbonate of lime	10.35
Water expelled at red heat	2.40
Silica, oxide of iron, etc	2.22
	100.00

Phosphorites include, besides those deposits already mentioned under that heading, the minerals staffelite, epiphosphorite, pyrophosphorite, eupyrchroite, hydro-apatite, monite, monetite, and other forms, all of which occur either in scattered pockets, incrustations, and concretions, or as radiated, botryoidal, and subcrystalline masses. Some of them occur scattered through certain phosphorites and rock phosphates, and are mentioned in connection with those deposits. They are rarely of any commercial importance.

Fibrous and concretionary phosphorites have been mined in small quantities at Amberg, Bavaria.

Thin seams of soft, whitish phosphorite, called osteolite, occur at Hanau, in Germany, but, as yet, the mineral has not been found there in sufficient quantities to be of commercial value.

ROCK PHOSPHATES.

This class of phosphates includes, as already mentioned, those deposits which, having no definite chemical composition and lacking the homogeneous nature and other fixed characteristics of a true mineral,

cannot be classified with *mineral phosphates.* They may be treated as *amorphous nodular phosphates, phosphatic limestone beds, guanos,* and *bone beds.*

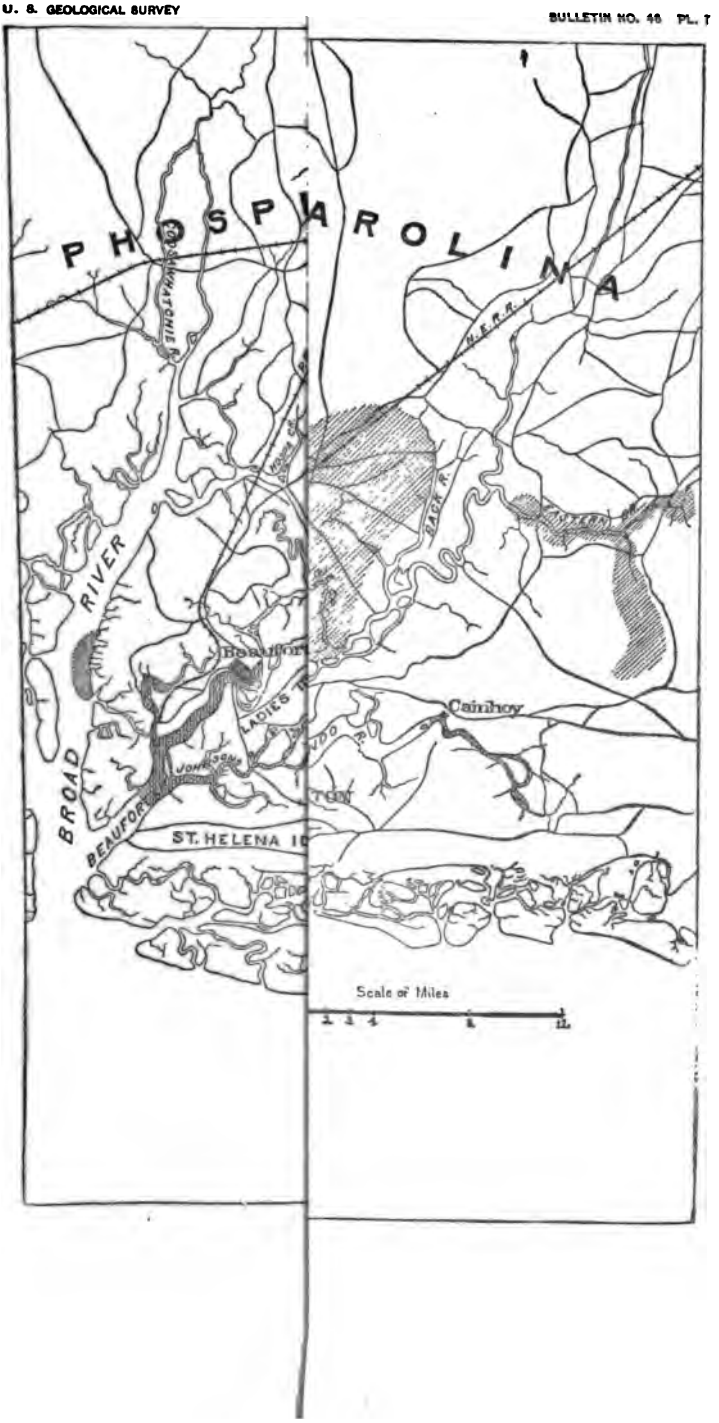
AMORPHOUS NODULAR PHOSPHATES.

This subdivision comprises the phosphate deposits of South Carolina, North Carolina, Alabama, Martha's Vineyard, some of the Florida deposits, the deposits of North Wales, England, Belgium, northern central and eastern France, and Russia. They generally consist of calcareous matter, more or less completely phosphatized, and occur either as loose nodules in a matrix of variable composition, or as a conglomerate in which the pebbles are phosphate of lime and the matrix is of a calcareous, phosphatic, siliceous, or ferruginous nature. They are the most important, commercially, of all the phosphate deposits. About 600,000 to 700,000 tons are yearly mined, of which, in 1884, 437,000 tons came from South Carolina and the rest mostly from England, France, and Belgium. On the other hand, the total output of all the apatite mines in America and Europe in the best years has not exceeded 50,000 tons.

AMORPHOUS NODULAR PHOSPHATES OF SOUTH CAROLINA.

The nature of the phosphate beds of South Carolina was recognized by Prof. C. U. Shepard, sr., before 1860, but the nodules were not put to any practical use until, in 1867–'68, Prof. F. S. Holmes and Drs. Pratt and St. Julien Ravenel, after showing by numerous analyses their richness in phosphate of lime, urged the formation of a company for mining these valuable deposits. Through the energy of Professor Holmes and Mr. G. T. Lewis, of Philadelphia, the first company for mining phosphate in South Carolina was organized in 1868. It was known as the Charleston Phosphate Mining and Manufacturing Company. Since that year no less than fifteen large mining establishments have been started in South Carolina, of which some of the more important are the Bradley, Pinckney, and Bolton, in Berkeley County, and the Coosaw and Oak Point properties, in Beaufort County.

Nodular phosphatic deposits are found at intervals all along the Atlantic Coast of the United States, from North Carolina down to the southern extremity of Florida, but the richest beds occur in South Carolina, in a strip of country running from Broad River 60 miles along the coast in a northeast direction. The belt has a width of from ten to twenty miles. The phosphate does not occur continuously over this region, but in patches, sometimes having an area of many square miles and again only covering a few acres. In this whole area of more than nine hundred square miles, the hills rarely rise to a height of over ten to fifteen feet above high-water level, and the country is cut up into islands and peninsulas by the numerous tide-water inlets and creeks. The Tertiary deposits form a fringe along the Atlantic Coast and the *Gulf of Mexico from* New Jersey to Texas, but are best developed in the


PHOSPHATE
CAROLINA
BROAD RIVER
Beaufort
Cainhoy
ST. HELENA
Scale of Miles

central portion of this extensive belt. The Claiborne marls, the Santee buhrstones and limestones, and the shell sands of Alabama are the lowest beds of this series. Beneath them lie the Pedee marls, which belong to the secondary formation and contain fossils resembling those from the Chalk of Europe. Immediately over this formation in South Carolina are the Eocene marls. These beds are very extensively developed in that State and are called by Mr. Ruffin "The Great Carolina marl bed," which is divided into three divisions, known, in an ascending order, as the Santee River, Cooper River, and Ashley River beds. The whole formation is about seven hundred feet deep and contains 55 to 95 per cent. of carbonate of lime. It is one of the most important marl beds in the world, on account of both its extent and its agricultural value. The upper part of the Ashley marl contains a great number of fossil shark teeth and cetacean bones, and has been called by Professor Tuomey "the fish bed of the Charleston basin." Overlying this "fish bed" is a deposit of sands and clays of very irregular thickness and containing many shells. The bed sometimes runs out altogether and at other times is several feet in thickness.[1] It is directly overlaid by a bed containing many shark teeth and cetacean bones, as well as the remains of the mastodon, megatherium, elephant, deer, horse, cow, hog, muskrat, and other land animals. Besides these animal remains, the bed contains very numerous irregularly shaped nodules containing 25 to 70 per cent. of phosphate of lime. This is the bed that is worked for phosphates (see Figs. 27, 28, and 29). Sometimes the underlying stratum has not existed or has been eroded and the nodule bed rests directly on the Eocene marls. It is composed mostly of nodules, associated with a much smaller and very variable quantity of bones of land and sea animals, buried in a matrix of a variable character. Sometimes they are in a bed of highly siliceous sand, containing many flat pebbles of white quartz; at other times the matrix consists of ordinary clay or of sand and clay mixed. A light blue or green clay is also often seen.

The nodules are of very irregular shape and vary from the size of a pea to that of a mass weighing a ton or more. The larger masses, however, are often composed of a number of small nodules cemented together. With the nodules and the bones are associated numerous phosphatic casts of the interiors of shells, as well as masses, of rare occurrence, which have the appearance of fossil dung (coprolites). The nodules, like those of England and of France, are all more or less waterworn and rounded and are much bored by marine animals. It is generally the harder varieties that are most bored and most irregular in shape. This may be due to the fact that, being hard, they preserve their original irregular shape and the marks of the boring animals better than the softer varieties. The nodules vary in hardness from 2 to 4 and have a specific gravity of 2.2 to 2.5.[2] When a fragment is rubbed,

[1] F. S. Holmes: The Phosphate Rocks of South Carolina.

[2] Dr. C. U. Shepard, jr.: South Carolina Phosphates.

or, better, when two fragments are rubbed together, they give off an odor of decayed organic matter. They are marked by a complete absence of crystalline structures, though in some rare cases, as in the Bull River phosphate, a distinct concretionary structure is observable. The nodules generally contain casts of Eocene shells and, in some cases, marine bones and shark teeth. The bones of land animals, though mixed with the nodules, are never found embedded in them, showing that these bones were probably deposited after the formation of the nodules.

The nodules are found on the bottoms of most of the rivers running through the phosphate district, having been washed out of their original beds. These river deposits in many cases have proved to be of great commercial value. The nodules are, as a rule, of a much darker color than those of the land and are often black. They are sometimes very siliceous, the separate grains of sand being plainly visible to the naked eye. These grains are due to the sand in the marl before it was phosphatized. Such seems to have been the case with much of the Beaufort River phosphate. In some cases, however, the siliceous matter is probably due to the replacement of some of the carbonate or phosphate of lime in the original nodule by silica, and the result has been to make the nodule much harder. Such a silicifying action was probably due to the presence of soluble silicates in the river waters. In some places, as at the Bolton mine, the land nodules are also very siliceous, and possibly became so by having once formed the bottom of a river or a bay.

At least eleven varieties of nodules, differing much in their physical character, and often in their chemical composition, may be distinguished among the phosphates taken out of the South Carolina beds. These are:

(1) A jet-black variety with a bright, shining, glossy enamel of the same color. It is very rare and generally occurs in small patches. It contains numerous fossils and shells. It is found in Parrot Creek (see map, Pl. I).

(2) A brown variety with a bright enamel of the same color. It is very rich and is found in considerable quantities at the Bradley mine and on the land of the Charleston Mining and Manufacturing Company.

(3) A light-brown variety with little or no enamel. It bleaches white when exposed to the sun and is found on the land of the Bradley Company, of the Charleston Mining and Manufacturing Company, and in many other localities.

(4) A light, chalky variety containing many shells and generally poorer in quality than the varieties mentioned above. It is very widely distributed over the South Carolina phosphate region, and is simply marl which has not been so highly phosphatized as the harder and darker varieties.

(5) A dark grayish-black variety with little or no enamel. It is very siliceous and contains many shells. It is generally found in rivers, and is especially characteristic of the Stono River district.

(6) A gray variety composed of a mass of shells and transparent siliceous sand, cemented together by a phosphatic cement. Sometimes shark teeth are included in the mass. At times it is hard and compact, and at others it is loose, soft, and porous. Such varieties are found in large quantities in the Beaufort River. They are often mixed with a much better quality of nodule which raises the average phosphatic contents.

(7) A dark-gray, phosphatic conglomerate, in which the pebbles are quartz and feldspar, varying from the size of a mustard seed to that of a buckshot. The matrix is a dark-gray, phosphatic marl. This variety is very rare in South Carolina, but is found in small quantities in the Bull River district.

(8) Nodules having a black enamel and a light or dark gray interior. They contain many shell casts and are found in the Coosaw River and on the Edisto River at Fishburne's mine.

(9) A variety consisting of a mass of concentrically laminated nodules cemented together with a matrix of marl containing many shells. This variety is rare and was found only in the Bull River. It is generally rich in phosphatic matter.

(10) A ferruginous, rusty-brown variety, very siliceous and of poor quality.

(11) Brown or black masses having the general appearance of fossil dung (coprolites) and probably of that nature. They are hard and very rich in phosphate of lime. Real coprolites are of rare occurrence.

Occasionally large, flat, non-concretionary masses are found, which are highly phosphatized on the upper side, while toward the lower side the mass grows poorer and poorer in phosphates, until it differs but little in composition from the underlying marl. In such cases the phosphatized part of the rock is of a darker color than the other part. The upper side is also much smoother and harder than the lower side, which is often very jagged and is sometimes almost as soft as the underlying marl. This formation shows that in some cases at least the phosphatization has gone from above downward. Such a process is also proved by the fact that the marl immediately underlying the phosphate bed contains sometimes 20 to 30 per cent. of phosphate of lime,[1] while this quantity decreases with the depth until, at a few inches below the nodule bed, it contains only 10 to 20 per cent. According to Professor Holmes, the marl is much richer in phosphate of lime in those places where it is overlaid by nodules than where no nodules are found.

Some of the varieties of nodules have been found to grow poorer in phosphoric acid as the center of the mass is approached. This is espe-

[1] Dr. C. U. Shepard, jr.: South Carolina Phosphates.

cially true of those nodules which are coated with an enamel, it being invariably the case that the hard, enamel like crust is much richer than the soft and less compact interior. In this peculiarity the South Carolina nodules resemble many of those of England and the other phosphate localities in Europe. The phenomenon is dwelt on as one of the strongest arguments for the theory originated by Professor Holmes, that the nodules have been formed by the phosphatization of lumps of

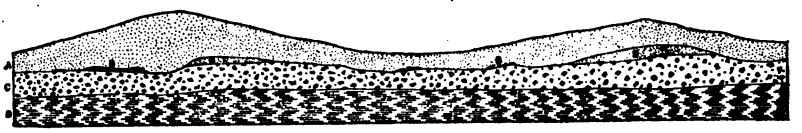


FIG. 27. Section ENE. and WSW. through Pinckney's phosphate field, South Carolina. A, sand; B, ferruginous sand; C, phosphate rock; D, Ashley marl. Scale: 1 inch = 60 feet.

marl. It may, however, be mentioned that a similar condition of the nodule could be produced by the action of waters containing carbonic acid, which would tend to leach out the carbonate and leave the less soluble phosphate of lime. Of course this action would be more pronounced on the exterior than in the interior of the nodule, and consequently the result would be a mass much richer in phosphate of lime on the outside than in the inside.

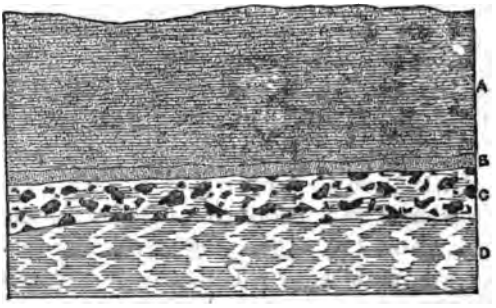


FIG. 28. Average section in Pinckney's phosphate mine, Berkeley County, South Carolina. A, clay sand; B, ferruginous sand; C, phosphate rock; D, Ashley marl. Scale: 1 inch = 6 feet.

The nodule bed varies in thickness from a few inches to about two feet and a half, the average being about seven to nine inches. It is only when the nodules are found in a pocket or depression in the underlying marl that the thickness reaches much over two feet, and even under such circumstances such a thickness is of very rare occurrence. The yield of phosphate per acre varies, not only with the thickness, but also with the compactness of the nodular stratum, as sometimes the nodules are packed as close as cobblestones in a road, while at others they are scattered loosely in the sand or clay matrix. The average yield of clean, dry phosphate is three hundred to twelve hundred tons per acre. The phosphate bed is thought by professor Holmes to be of Post-Pliocene age. In

some places it crops out on the surface and at others is found at a much greater depth. Under the city of Charleston it is found at a depth of over sixty feet.[1] Where the bed does not appear on the surface it is covered by alluvial deposits, consisting of clay, sand, or marl, or of strata of all three. Occasionally there is a stratum of highly ferruginous sand or gravel, sometimes indurated into a regular "hard-pan," directly overlying the phosphate bed and from one to ten inches thick (Figs. 27, 28, and 29). Sometimes this ferruginous substance has penetrated the whole bed to a depth of several inches and cemented the upper nodules into a solid mass; while the lower part of the bed is much looser and more easily mined. Again the sand overlying and intermixed with the nodules has sometimes been cemented together, especially in river bottoms, by the action of soluble silicates. Such has been the case with the phosphate in parts of the Stono River. Here the nodules have in some places been completely permeated by silica and form a solid floor on the river bottom.

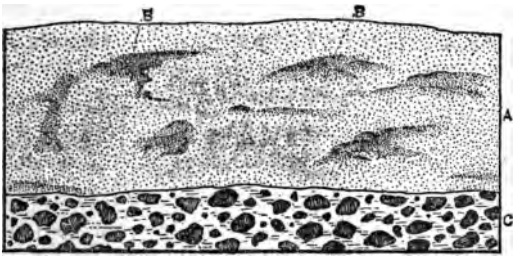


FIG. 29. Section in one of Fishburne's pits, South Carolina. A, sand; B. ferruginous sand; C, phosphate nodules in clay matrix. Scale: 1 inch = 7 feet.

The following sections by Dr. C. U. Shepard, jr., show the general mode of occurrence of the superficial beds of phosphate:

A. Land deposits:

I. *Soil and subsoil.* A few inches to a foot in depth.

II. *A light-colored, siliceous clay,* iron stained in places, and containing much fine, transparent sand, and minute scales of silvery mica, with little calcareous matter, one foot or more in thickness.

III. (Wanting in the more superficial beds.) *A blue, argillaceous marl,* probably altered marsh mud. It does not adhere to the tongue or give an argillaceous odor. Fragments of recent shells occur in this deposit. Its depth is about two feet.

IV. *A thin layer of coarse sand,* one to three inches in depth.

V. *The phosphate nodules* in either a loose, siliceous or a tenaceous, bluish or rich buff-colored, argillaceous marl, frequently accompanied with abundant fossil bones and teeth. The upper nodules are often harder, the lower softer, and at some land localities exhibit a gradual transition, by loss of cohesion and decrease of phosphatic contents into

VI. *A marl,* highly phosphatic toward the rock-bed, and containing occasionally 20 to 30 per cent. of phosphates, but at the depth of a few inches containing only 10 to 20 per cent. of those constituents.

[1] Dr. C. U. Shepard, jr.: South Carolina Phosphates.

VII. *Argillaceous or arenaceous marls*, containing 7 to 10 per cent. of phosphates.

B. River deposits:

Beneath the river deposits occur either—

I. *A gray marl*, sometimes in nodules resembling phosphate, with 5 per cent. of phosphates, underlaid by

II. *A white, hard marl* inclosing phosphate grains and containing 3 to 5 per cent. of phosphates (Wando River); or

I. *A green sand* with some clay and rich in black phosphatic grains, occurring with the phosphatic rock and beneath it, containing 15 per cent. of phosphates.

II. *Soft and hard marls* several feet in thickness, and containing 10 to 15 per cent. of phosphates (Stono River); or

I. *Hard marls*. Poor in phosphates (¼ to 1 per cent.) unless their tops be coated with phosphate rock (Coosaw River).[1]

It is difficult to calculate the yield of river nodules per acre, as the currents have heaped them up in some places and carried them away from others.

As will be seen from the accompanying map by Dr. C. U. Shepard, jr. (Pl. I), there are three principal localities in the phosphate region where active mining operations are now carried on. It is not, however, all over these areas, but only in certain parts of them, that the nodules are found. Nor are they the only places in South Carolina where phosphates occur, but they are the districts where they are found at a depth beneath the superficial deposits not too great to permit profitable mining.[1] The first of these regions lies north and east of Charleston and stretches from the Wando River and the eastern branch of the Cooper River on the northeast to Rantowles Creek and Stono River on the southwest. In this area are some of the largest phosphate diggings in South Carolina, including as it does the Bradley, Charleston Mining and Manufacturing, the Magnolia, Bolton, and Black and Williams's mines. There also are the river deposits in the Wando, Stono, and Cooper Rivers. Large quantities of small nodules of excellent quality have been obtained from the bed of the upper part of the Wando River. Phosphate of good quality has also been gotten from the bed of Stono River, but the deposit forms in some places such a solid floor on the river bottom that mining operations at the present low price of phosphate would be unprofitable. Mainly on account of their inaccessibility the deposits in the eastern branch of the Cooper have not been much worked.

The second of the three principal phosphate districts is due west of the locality last described and extends from the Edisto River on the east to Horseshoe Creek on the west, including the river deposits in these two streams. The phosphate found in this region is of excellent quality, but does not occur in a continuous bed or at a constant depth. Consequently it can be profitably mined in few places. It occurs largely in pockets and patches on the underlying bed.

The third locality where phosphate exists at a conveniently accessible depth extends with intervals from the Bull to the Broad Rivers, and

[1] Dr. C. U. Shepard, jr.: South Carolina Phosphates.

includes not only the deposits in these rivers, but also the deposits in the Coosaw and Beaufort Rivers and those on Chisholm's Island. This area is essentially a river mining district, though phosphate of good quality is mined on parts of Chisholm's Island by the Pacific Guano Company and by Messrs. Wiley and Gordon. Nodules of excellent quality are obtained from the bottoms of the Bull and Coosaw Rivers, but those of Beaufort River are generally very siliceous, the separate grains of sand being plainly visible to the naked eye.

Outside of the localities mentioned above, phosphatic nodules have also been obtained from the upper part of Hospa Creek and from the Coosawhatchie River (see map, Pl. I). Besides the bed of phosphatic nodules already described, other beds have been found in boring artesian wells in Charleston and the neighborhood which are at a much greater depth and are of a similar nature. Dr. C. U. Shepard, jr., in speaking of these borings, says:

> The samples thus collected have been carefully examined and analyzed, the most important contribution to our knowledge being the discovery of the existence of several deeper layers of phosphate rock, occurring at the depth of 300 feet from the surface, and, in the form of isolated pebbles, to a much greater distance. These lower deposits are probably not thicker than a few inches, and consequently they lack all but scientific interest.

The phosphate of South Carolina is obtained from the land and from the river bottoms. The mining on the land is done in open trenches. The area to be mined has to be ditched in order to drain it before mining operations can be begun. Sometimes it is necessary to build embankments, to prevent the diggings from being flooded in stormy weather. At the Bolton mine, on Stono River, high tides sometimes rise two feet above the level of the land. Drainage is, in some mines, hastened by the use of steam pumps. It does not usually pay, unless the phosphate is of extraordinary quality, to remove more than eight or nine feet of overlying earth. The Pacific Guano Company, however, has lately introduced the use of a steam excavator to dig the nodules, and it is supposed that work can be profitably carried on at a greater depth with this machine than with pick and shovel.

The phosphate is carried on cars, generally drawn by an engine, from the mines to the washers. Here it is broken by machinery into coarse fragments not larger than about five inches in diameter, and then passed into the washers, where it is freed from the adhering sand and clay. Several different kinds of washers are used. The most common one is a long trough, in which revolves a shaft armed with a projection in the form of a broken helix. The trough is inclined at a small angle. The nodules are passed from the breakers to the lower end of the trough and are forced up the inclined plane by the revolving shaft against a strong stream of water. Sometimes the phosphate is washed in a revolving cylinder perforated with holes and supplied on the inside with spiral flanges of steel. A stream of water is thrown into the cylinder

through an iron pipe. After passing through the washers the nodules fall on an iron screen, which separates the large masses from the smaller pieces. Sometimes two or three screens having different-sized meshes are used. The small-sized product is of lower grade than the large, as it is mixed with numerous siliceous pebbles which have gone through the screen with it.

The next step is to dry the nodules. This is done either by burning them with wood in large sheds, which sometimes hold several thousand tons, or by passing hot air through the mass. Sometimes the nodules are treated with fire and hot air combined. In this way they are freed from the 12 to 18 per cent. of moisture which they contained after being washed and are ready for shipment. On cooling, the nodules absorb about 1 per cent. of moisture, and such is their porosity that they can be made to absorb 5 to 15 per cent. of water.[1] The drying of the nodules takes 35 to 40 cords of wood for 1,000 tons of nodules, and the process lasts thirty-six to forty hours. The drying and burning of the phosphate not only save the freight on the water which it originally contained, but also make it better fitted for manufacturing purposes.

The nodules in the river bottoms are now obtained by dredging boats, though, a few years ago, large quantities were obtained by negro divers and with oyster tongs. The dredging scoops have to be very strongly built in order to break through the nodular stratum. The boats are held in position at the four corners by what are called "spuds." These are strong square poles with iron points. They are dropped into the water before dredging is begun, and go through the nodule stratum and down into the bed below, thus affording a firm support to the boat. The nodules are thrown from the scoop into the washer, which is on a lighter alongside the dredging boat. The washer, in some cases, is the same as those used by the land-mining companies; but often it consists of a truncated cone, with perforated sides, revolving on a horizontal axis. It is supplied on the inside with steel spirals, arranged around the side like the grooves in a rifle. Into both ends of the cone heavy streams of water flow. The nodules are dumped by the dredge into the small end of the cone and come out at the large end. They are then removed by a derrick to another lighter and towed to shore.

Besides the ordinary dredging machine, several other contrivances are used for raising phosphate from river bottoms. The owners of the Sea Island Chemical Works, instead of using the ordinary dredging scoop, have a contrivance consisting of six large claws which open when they descend, and close, forming a kind of bucket, when they rise. It is said that one of the machines which this company owns can dredge in 50 to 60 feet of water, while the ordinary dredging boat cannot raise the phosphate in over 20 feet of water. Another dredge has been lately introduced by Mr. Brotherhood and is known as the Broth-

[1] *Dr. C. U. Shepard, jr.*: South Carolina Phosphates, 1880.

erhood dredge. It consists of a revolving chain of thirty-two buckets, and is very similar to the dredge used to deepen the channel of the St. Lawrence River some years ago.

The deposits of South Carolina, though of low grade compared with some others, are now more generally used than any other known phosphate. The output of the mines, which is yearly increasing, is shipped to the North, South, and East by sea and to the West by rail. This popularity is due, not only to the cheapness of the phosphate ($5 to $6 per ton in 1886), but to the many good qualities of the low-grade acid phosphate made from it. The fact that the nodule bed extends, at an accessible depth, over many miles of country, the easy approach for large vessels up to the very mines, the abundance of water, fuel, and labor, and a climate that permits mining operations to be carried on throughout the whole year, all combine to make the South Carolina phosphates the cheapest and consequently the most productive source of supply of this material.

The mode of formation of the South Carolina nodules has been a matter of considerable dispute. Professor Holmes thinks that the surface of the Eocene marl was worn, by the action of boring animals and of erosion, into numerous lumps and balls. These, with bones of sea animals, were washed upon the seashore and, as the coastline began to rise, were collected into salt-water lagoons and swamps. Numerous quadrupeds came to lick the salt, and deposited their fæces and often died here. Hence the presence of bones of land and sea animals in the phosphate beds. The phosphoric acid in the fæces and carcasses of these animals phosphatized the lumps of marl and thus formed the phosphatic nodules.

Prof. N. S. Shaler thinks that the nodules, in some cases, have been formed by concretionary and segregating action at the bottom of swamps. Many facts, such as the frequent occurrence of phosphatic nodules in patches, and often in concave basins, as in Russia, as well as their association with peaty beds, as in North Carolina, seem, in many cases, to strongly favor this theory. Phosphatic nodules have also been found at the bottom of beds of limonite in the Ohio Valley. Professor Shaler thinks that the nodules were scattered sparingly in the deposit in which they were formed and that they were concentrated in their present position by the erosion of the original bed.[1]

Analyses of South Carolina rock phosphates, by Dr. C. U. Shepard, jr., in South Carolina Phosphates, Charleston, 1880.

An average of several hundred analyses gave:

	Per cent.
Phosphoric acid	25 to 28
Equivalent to bone phosphate of lime	55 to 61
Carbonic acid	2.5 to 5
Equivalent to carbonate of lime	5 to 11

[1] Proc. Boston Soc. Nat. Hist., vol. 13, 1869–'70, p. 222.

	Per cent.
Sulphuric acid	0.5 to 2
Lime	35.0 to 42
Magnesia	Trace to 2
Alumina	Trace to 2
Sesquioxide of iron	1.0 to 4
Fluorine	1.0 to 2
Sand and silica	4.0 to 12
Organic matter and combined water	2.0 to 6
Moisture	0.5 to 4

Table of analyses of South Carolina rock phosphates by Dr. C. U. Shepard, jr.

	Stono River light-colored nodule.	Stono River dark-colored nodule.	Stono River nodule.	Ashley River land nodule, dried.	Cooper River land deposit.	Chisholm's Island nodule, dried.	Bull River nodule, dried.	Coosaw River nodule, dried.	Coosaw River nodule, dried.
Moisture	3.68	.....	1.50	0.00	.10	0.84	0.79	0.57	0.66
Organic matter and combined water	4.78	.....	5.59	5.26	.07	4.22	5.80	4.31	3.75
Carbonic acid	4.68	4.28	3.89	4.47	3.55	3.54	3.61	3.79	4.34
Equal in carbonate of lime to	10.69	9.73	8.84	10.04	8.06	8.04	8.19	8.61	9.84
Phosphoric acid	25.61	26.68	25.75	27.01	27.11	27.26	25.14	27.26	26.78
Equivalent in bone phosphate to	55.91	58.24	56.21	58.95	59.18	59.50	54.88	59.51	58.46
Sand	11.55	12.41	11.77	11.37	15.39	9.06	13.30	9.06	11.77

Analysis of South Carolina rock phosphate from Oak Point Mine, by Dr. C. U. Shepard, jr.

Bone phosphate of lime	58.66
Carbonate of lime	6.90

Analysis of phosphatic nodules from Bulow mine, property of William L. Bradley, by R. A. F. Penrose, jr.

Bone phosphate of lime	62.039
Carbonate of lime	6.914
Organic matter and moisture	5.106

AMORPHOUS NODULAR PHOSPHATES OF NORTH CAROLINA.

Deposits of phosphate of lime have been known to exist in the flat country near the coast of North Carolina for several years, but not much attention was paid to them until 1884, when, under the direction of Dr. Dabney, of the agricultural station of that State, they were thoroughly examined. The result seemed to show that the phosphates were either too scanty in quantity or too poor in quality to be of much commercial importance. They are found in the southeastern part of North Carolina, and principally in the counties of Sampson, Duplin, Pender, Onslow, Columbus, and New Hanover.

The deposits are of two kinds: (1) Beds of nodules, resembling very much the South Carolina beds and (2) a conglomerate in which the pebbles are phosphate and the matrix a white calcareous rock.

(1) The beds of nodules overlie the Eocene marl and consist of numerous phosphatic nodules, shark teeth and bones, associated in a sandy matrix or in a shell marl. Generally, the bed immediately overlies a stratum of shell marl and is occasionally overlaid by a similar stratum. Sometimes the underlying bed is replaced by a deposit of a pale-green, indurated sand, containing shark teeth and other bones. The two following sections will show the mode of occurrence of these phosphates:

1. Soil, sand or clay, 5 to 10 feet.
2. Shell marl, 5 to 10 feet.
3. Bed bearing phosphate nodules, 1 to 3 feet.
4. Sea-green, sandy marl, 2 to 4 feet.
5. Ferruginous hard pan, 6 to 12 inches.
6. Interstratified lignites and same sands as in 4.

The above section was obtained in a canal on the land of Mr. N. Daniel, Sampson County. Fragments of lignite are sometimes associated with the nodules.

Section 2, from the beds on J. W. Best's farm, Duplin County.

1. Sandy soil, 1 to 10 feet.
2. Nodule bed, 1 to 2 feet.
3. Shell marl.

The nodules are of a lead-gray color and vary from lumps the size of a man's fist to masses weighing several hundred pounds. The average size is larger than that of the South Carolina nodules. They vary in composition from the close, compact, and homogeneous masses found in some places in Onslow County, to the coarse-grained and highly siliceous rock of Sampson and Duplin Counties. The latter variety contains considerable quantities of sand, which can be distinguished with the naked eye, and occasionally siliceous pebbles the size of a chestnut. In fact, the nodules are often a phosphatic sandstone, in which the grains of sand are cemented by phosphatic matter. Occasionally they are found containing numerous Tertiary shells. Many shells are also found mixed with the nodules in the sandy matrix, and they preserve their most delicate outlines in a state of great perfection, while the nodules are much rolled and rounded. These facts would seem to show that the shells were brought into their present position by the animals that once inhabited them after the bed of nodules had been formed. A similar condition has been observed in the English beds of phosphate nodules. The North Carolina nodules are much bored by mollusks and in every respect resemble those from the Russian Cretaceous formation.

The nodules all tend toward flat shapes, in which they differ from those of South Carolina, which have no definite form. One specimen found measured 18 inches long 12 wide and 2 thick. This flat character would seem to favor the idea that the nodules were formed by the phos-

phatization of the surface of a bed of sandy marl. The phosphate, having a tendency to segregate, formed in some places richer than in others. Then, when the bed was exposed to erosion, only the parts which were strongly enough cemented together survived. Often, around the siliceous pebbles in a nodule, concentric bands of phosphate of lime may be observed, showing its strong tendency to form in segregations.

These deposits have not as yet been put to any commercial use. They are of a low grade, averaging only about 45 per cent. phosphate of lime, and occur only in small patches of from one to twelve acres.

(2) The second variety of phosphate deposits found in North Carolina belongs to the class of phosphatic conglomerates. They are found in New Hanover and Pender Counties and consist of a mass of Tertiary shark teeth, bones, nodules, and quartz pebbles, all well rolled and rounded and cemented together, along with grains of greensand, in a calcareous matrix. At Castle Hayne, New Hanover County, they occur in a bed sometimes over six feet deep. The largest pebbles and nodules are nearest the top of the formation and never exceed the size of a horse-chestnut. They grow smaller with the depth, and at six feet they are not larger than an apple seed. The character of the whole mass of the deposit also varies very much with the depth. The top of the bed is a hard and solid rock, but at two feet it begins to get softer, and at three to four feet the conglomerate bed is simply a mass of loose, calcareous marl containing pebbles. The section below, from near Castle Hayne, N. C., will show the nature of this bed.

1. White sand 0 to 3 feet.
2. Brown to red, ferruginous, sandy clay or clayey sand, 1 to 3 feet.
3. Green clay, 6 to 12 inches.
4. Dark-brown, indurated peat, 3 to 12 inches.
5. White, calcareous marl, 0 to 2 feet.
6. White shell rock, 0 to 14 inches.
7. Phosphatic conglomerate rock, 1 to 3 feet.
8. Gray marl containing smaller nodules than the overlying bed, 2½ to 4½ feet.
9. Light-colored, calcareous marl, containing nodules which are smaller than those in the overlying beds and which grow fewer and smaller at a depth. Many shells.

The line between the shell rock (6) and the conglomerate bed (7) is very sharply drawn. There are occasionally a few nodules found in the shell rock near the line of contact, which may have been derived from the conglomerate. The surfaces of all the beds are very uneven, especially that of the calcareous marl in the above section, which occurs only in patches on top of the shell rock (Fig. 30).

Near Wilmington, N. C., the following section was obtained:

1. Sandy soil, 2 feet.
2. Greensand bearing a few phosphatic nodules about the size of a pea, 4 feet.
3. Gray marl, 6 feet.
4. Limestone rock bearing a variable amount of nodules, of the same size as near Castle Hayne.

The nodules in 4 sometimes make up as much as three-fourths of the contents of the bed; at others they occur scatteringly through the

rock, and occasionally are not found at all. They are kidney and egg shaped and generally much less bored and irregular than the South Carolina nodules. They vary from gray to greenish black in color and have a specific gravity of 2.6 to 2.7.

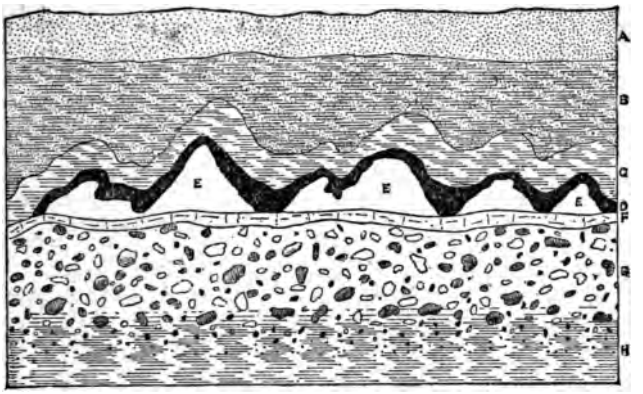


FIG. 30. Strata overlying the phosphate bed at Castle Hayne, New Hanover County, North Carolina. A, sand; B, ferruginous, sandy clay; C, green clay; D, indurated peat; E, calcareous marl; F, white shell rock; G, phosphate conglomerate; H, marl containing smaller nodules. Scale: 1 inch = 5 feet.

Two companies have been formed to grind this conglomerate rock and sell it for local use. The whole mass does not contain more than 10 to 20 per cent. phosphate of lime, but it is said to have been successfully used as a fertilizer. The separate nodules are very variable in composition.

Table of analyses of North Carolina rock phosphates made at the North Carolina experiment station.

[I to XI. From neighborhood of Warsaw, Duplin County.]

	I.	II.	III.	IV.	V.	VI.	VII.
Moisture	0.92	1.57	1.08	1.79	1.73	1.06	0.63
Samples dried at 212 degrees F. contain sand and insoluble matter	38.09	28.92	42.96	5.17	59.47	29.46	37.36
Carbonate of lime	3.81	2.43	4.18	5.91	3.12	54.89	4.96
Phosphate of lime	45.16	57.18	42.46	37.28	28.19	3.90	44.51
Equivalent to phosphoric acid	20.10	26.19	19.45	17.07	12.91	25.15	20.39

	VIII.	IX.	X.	XI.
Moisture	0.66	0.39	.....	.....
Sand and insoluble matter	30.44	36.59	45.62	44.73
Carbonate of lime	6.30	6.30	4.59	2.30
Phosphate of lime	53.03	45.78	39.86	39.33
Equivalent to phosphoric acid	24.29	20.97	18.26	18.01

Table of analyses of North Carolina rock phosphates etc.—Continued.

[XII to XVI. From neighborhood of N. A. Faison's, Duplin County.]

	XII. White compact.	XIII. Gray compact.	XIV. White gritty.	XV. Gray.	XVI. Common black.
Moisture	2 07	2. 50	0. 77	2. 70	0. 81
Sand and insoluble matter	1. 49	0. 05	32. 79	0. 64	45. 91
Carbonate of lime	12. 00	8. 98	1. 45	7. 07	5. 84
Bone phosphate	71. 82	76. 82	7. 42	76. 54	36. 02
Equivalent to phosphoric acid	32. 90	35. 19	3. 40	35. 06	16. 50

[I to XV. Nodules from Sampson County, N. C.]

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Sand and insoluble	47. 18	47. 41	70. 78	54. 96	1. 58	51. 75	32. 16	44. 99
Carbonate of lime	5. 91	5. 27	4. 20	3. 91	9. 55	4. 52	3. 91	5. 25
Bone phosphate	28. 09	38. 31	20. 24	32. 05	69. 55	32. 53	50. 73	37. 70

	IX.	X.	XI.	XII.	XIII.	XIV.	XV.
Sand and insoluble	36. 04	52. 53	49. 34	29. 41	51. 93	50. 42	53. 43
Carbonate of lime	4. 71	5. 68	4. 66	5. 68	6. 43	1. 86	6. 43
Bone phosphate	44. 82	32. 22	33. 62	38. 09	29. 93	35. 52	29. 47

[I to II. Nodules from Pender County, N. C.]

	I.	II.
Sand and insoluble matter	61. 96	24. 77
Carbonate of lime	4. 32	15. 55
Bone phosphate	21. 02	47. 50

[I. Nodules from phosphatic conglomerate from New Hanover County, N. C.]

	I.
Sand	43. 66
Carbonate of lime	34. 56
Magnesia	0. 86
Potash	0. 39
Oxide of iron and alumina	0. 56
Phosphate of lime	19. 99
Sulphuric acid	Trace
Chlorine	Trace
	100. 02

[II to VIII. Nodules from phosphatic conglomerate from New Hanover County, N. C.]

	II.	III.	IV.	V.	VI.	VII.	VIII.
Sand and insoluble matter	22. 07	33. 52	.....	18. 50	20. 02	3. 25	31. 66
Carbonate of lime	42. 12	20. 45	.....	39. 04	42. 12	51. 34	15. 94
Phosphate of lime	20. 50	33. 97	30. 90	25. 34	22. 68	31. 59	42. 09
Equivalent to phosphoric acid	9. 39	15. 57	14. 16	11. 61	10. 39	14. 57	19. 28

Table of analyses of North Carolina rock phosphates etc.—Continued.

[I to IV. Phosphatic conglomerate of New Hanover County, N. C.]

	I.	II.	III.	IV.
Sand and insoluble matter	20.28	24.96	42.98	35.48
Carbonate of lime	57.29	54.71	10.12	51.81
Phosphate of lime	11.81	16.42	26.64	6.40
Equivalent to phosphoric acid	5.41	.....	12.57	2.83

[I. Phosphate conglomerate from New Hanover County, N. C.]

Carbonate of lime	64.26
Phosphate of lime	11.16
Equivalent to phosphoric acid, 5.11.	
Magnesia	0.81
Potash	0.40
Sulphates and chlorides	Trace
Sand, soluble silica, oxide of iron, alumina, etc., undetermined	23.37
	100.00

AMORPHOUS NODULAR PHOSPHATES OF ALABAMA.

The phosphate deposits of Alabama belong to the Cretaceous formation and are found in two parallel belts running across the State. The following very general section, in an ascending order, will show their positions:

(1) Eutaw group.
(2) Phosphate stratum.
(3) Rotten limestone formation.
(4) Phosphate stratum.
(5) Ripley group.

The Cretaceous formation of Alabama probably corresponds to the Upper Chalk of Europe, which also, in some places, contains beds of phosphatic nodules. It runs from the western part of Georgia in a WNW. direction through Alabama into Mississippi, where it takes an abrupt curve to the north. After passing through the western and northern part of Mississippi it enters Tennessee and runs through that State almost to the Kentucky boundary line. The phosphate deposits, it is said, can be traced along a considerable length of this formation, but, as far as has yet been discovered, it is only in Alabama, and there only in a few places, that the deposits are of considerable extent. In that State the Cretaceous strata dip gently to the south, and as a result of this dip the nodule bed, at the base of the Rotten Limestone, is found at ten to twenty miles north of the one at the summit of that formation.

The general character of the two deposits is very much the same. They are composed of shells, phosphatic nodules, shell casts, and fossils, all much worn, broken, and rounded, and buried in a matrix of a soft, white or gray limestone. The nodules are generally flat in their general shape and chestnut brown in color, and average, in size, from one-

half an inch to three inches in diameter. They are very irregular in form and occasionally show one side which is completely phosphatized and another which is composed largely of carbonate of lime. This is strong evidence for the theory of their formation by the phosphatization of the surface of a calcareous bed, as mentioned in the case of the North Carolina deposits. The fossils of the two beds differ considerably. Ammonites are very plentiful in both, but *Hippurites* and *Baculites* were found in much larger quantities in the lower bed than in the upper one. The following two sections will show the different relations of the two beds:

(*a*) Upper bed (at Coatopa):

1. Greensand containing nodules and shell casts, but numerous only at the base, 4 feet.
2. Soft, calcareous rock containing nodules, 1 foot to 1½ feet.
3. Rotten limestone.

(*b*) Lower bed (at Hamburg):

1. Greensand bearing some casts and nodules, 0 to 5 feet.
2. Gray limestone containing many nodules, 5 feet.
3. Hard, indurated sand ledge, containing shells, 8 to 12 inches.
4. Yellow sand containing shells, 2 feet.
5. Ferruginous sand containing specks of mica, about 30 feet.
6. Indurated sand ledge containing shells 8 to 12 inches.
7. Yellow sand containing shells, 2 feet.
8. Greensand.

The section of the upper bed is well seen at the town of Coatopa, in Sumter County. The Greensand here is often oxidized and has a rusty-red appearance; it composes a large part of the surface soil in the neighborhood and forms part of the so-called "Black Belt," famous for its fertility. It contains many phosphatic shell casts, but is generally richest in them near the line of contact with the underlying bed, where they sometimes make up 50 per cent. of the whole mass. Occasionally they cover the whole surface of the ground and must be carted away in order to permit agricultural operations. The underlying bed contains many more nodules and shell casts than the Greensand. Sometimes it is almost a solid mass of them with a soft, gray, calcareous matrix. The bed is from 1 foot to 1½ feet thick and seems to underlie a large extent of country. In some places the nodules and fossils are more scattered in the bed than in others, and in still other places the bed has been entirely eroded away and the Greensand comes into direct contact with the Rotten Limestone. Very few bones were found in this upper bed.

Outcrops of this same nodule bed can be seen near the Tombigbee River, at Moscow, and also at Livingston, on the Sucarnochee River. In the underlying Rotten Limestone there are no phosphatic nodules.

The section of the lower nodule bed is seen at numerous places all across the State. Thus it is found at Eutaw, Selma, Greenborough, Prattville, Wetumpka, and especially well at Hamburg, near Marion.

In this last place the surface is largely composed of greensand, though, in some places, this is washed off, exposing the phosphate-bearing bed. Where the ground has been much eroded and cut into gullies, it is covered by a solid sheet of nodules, phosphatized shell casts, fossils, ferruginous concretions, and unaltered shells. There is a much larger per cent. of the brown nodules here than in the upper nodule bed; but as in that bed, so here, the nodules are very few compared with the fossils and shell casts. The indurated ledge represented in the section seems to have the same general composition as the sand that underlies it, but to be in a hardened condition.

The phosphate deposits of Alabama are more difficult to mine than the South Carolina phosphates and cannot be shipped as cheaply. Consequently they have not as yet been put to any practical use. But they have been found in sufficient quantities in several places to become of considerable local importance. Among other places, they are found in considerable quantities on the land of Mr. J. F. Wiatt, near Coatopa, and of Mr. Spencer and Messrs. Davis, near Hamburg.

Table of analyses of amorphous nodular phosphates of Alabama.

[Northern belt. (*a*) The nodules and phosphatic casts of fossils from Spencer's field, Hamburg, Ala.]

	Phosphoric acid.	Bone phosphate	Analyist.
Nodule	22.00	48.00	W. I. Herzberg, University of Alabama.
Phosphatized shell	13.80	43.16	Do.
Surface nodules	38.00	82.84	John Daniel, University of Alabama.
Surface nodules	35.5	77.39	Do.
Surface nodules, sample 1 pound	25.66	55.88	Charles Gibson, Chicago.
Nodules from near Selma	26.1	56.90	John Daniel, University of Alabama.
Nodules from near Selma	25.8	56.24	Do.
Nodules from near Selma	36.0	78.48	Do.
Nodules from near Selma	38.0	82.84	Do.

[(*b*) Matrix of the nodules from Spencer's field, Hamburg, Ala.]

	Phosphoric acid.	Bone phosphate.	Analyist.
Matrix of nodules	5.12	11.16	E. M. Harris, University of Alabama.
Matrix of nodules	1.2	9.16	John Daniel, University of Alabama.
Matrix of nodules	4.65	10.14	L. L. Dean, University of Alabama.
Matrix of nodules	8.00	17.44	Do.
Blue matrix of nodules	2.2	4.80	Charles Gibson, Chicago.
White matrix of nodules	3.6	7.85	Do.

Table of analyses of amorphous nodular phosphates of Alabama—Continued.

[II. Southern belt. (Bulletin No. 5 of the department of agriculture of Alabama.)]

	Insoluble matter.	Phosphoric acid.	Bone phosphate.
Nodules from near Livingstone	8.48	1.10	2.40
Nodules from near Livingstone	15.02	.64	1.39
Shell casts and nodules from near Coatopa	9.38	14.56	31.78
Shell casts from Moscow	25.52	1.55	3.38

AMORPHOUS NODULAR PHOSPHATES OF MARTHA'S VINEYARD.

The phosphates of Martha's Vineyard occur as black or dark-gray nodules, varying from one-fourth of an inch to four inches in diameter, in two beds of Greensand. The beds are of Tertiary age and are well seen in the cliffs at Gay Head. They are each 18 to 24 inches thick and dip at an almost vertical angle. They are associated with beds of lignite, clay, and sand. The nodules are mixed with numerous bones of cetaceans, crustacean remains, and other fossils. The more southerly of the two beds contains 5 to 15 per cent. of nodules and bones, while the bed to the north contains in some places almost no nodules, and in others as much as 25 per cent. of them. The nodules have a water-worn appearance and have been much bored by marine mollusks. They give off a smell of decayed organic matter when two fragments are rubbed together, and have a hardness of about 3.

This deposit has not yet been put to any practical use. The nodules are probably too scattered in the bed and too expensive to mine to allow them to be of any commercial value.[1]

AMORPHOUS NODULAR PHOSPHATES OF FLORIDA.

Phosphate deposits have been found in various places in Florida, but as far as is yet known they are either of too small extent or of too poor quality to pay for mining. The only deposit which covers more than a few acres is found in Alachua County, near the central part of the State. The phosphate found here belongs to the subdivision of phosphatic conglomerates. The rock consists of small pebbles, from the size of a mustard seed to that of a pea, closely packed in a matrix of indurated calcareous marl. The pebbles are very compact, have a small conchoidal fracture and sometimes an enamel-like luster. They are creamy white to chestnut brown in color and are associated with

[1] It seems to me certain that these beds containing nodules were deposited in the delta of a large river and that the nodules, together with the greater part of the fossils with which they are intermingled, were derived from pre-existing strata in essentially the same manner as those which occur in the estuaries of the rivers near Charleston, S. C.

For a further description of these deposits see a report on the island of Martha's Vineyard, now in press, to appear in the Seventh Annual Report of the U. S. Geological Survey.—N. S. S.

worn and rounded bones and shells. Prof. C. U. Shepard, sr., thinks that many of the pebbles may be the worn casts of marine shells, while some of them seem to be fragments of coral. This conglomerate occurs in masses weighing from one to twenty pounds. The largest mass yet found was 18 inches long, 14 wide, and 4 thick. The pebbles occur in a bed covering about ten acres and are associated with pieces of a porous limestone rock, very common in the region. The bed varies from a fraction of a foot to five feet in thickness. Sometimes it crops out at the surface, and at others it is found at a depth of four or more feet. At Gainesville, a town 19 miles west of this bed, a similar rock is said to have been found, in boring an artesian well, at a depth of 248 feet.

The masses of rock are not nodules, but seem to be simply broken fragments. They are much weathered and rounded and are buried in sand.

In some places the pebbles, rounded bones, and coral fragments occur loose in a calcareous matrix, as if weathered out of the original conglomerate. Samples of pebbles from this loose material are said by one of the owners of this place (Dr. Simmons) to average 85 per cent. phosphate of lime, while the whole mass of the rock, as analyzed by C. U. Shepard, jr., averages about 48 per cent.

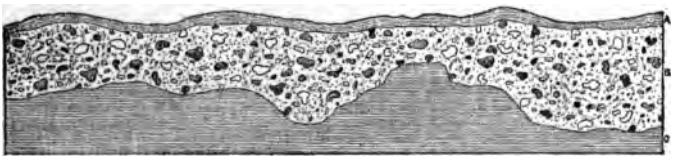


FIG. 31. Section in quarry at Rocky Hill, on Lochloosa Creek, near Magnesia Springs, Alachua County, Fla. A, sandy soil; B, calcareous nodules, white, brown, and purple, embedded in sand; C, spongy, calcareous rock, blending at a depth of 3 to 4 feet into a phosphatic rock. Scale: 1 inch = 8 feet.

On the northwest side of this bed runs a stream known as Lochloosa Creek, beyond which is a ridge rising sixty to seventy-five feet above the creek, and called Rocky Hill. The hill is overlaid almost entirely by a deposit of calcareous stones and pebbles, embedded in sand, which sometimes entirely runs out, and again reaches a depth of over six feet. Below is a soft, porous, calcareous rock, which is of a spongy consistency and hardens on exposure to air. It is quarried for building the chimneys and foundations of houses. In one of the quarries examined this formation gradually blended, at a depth of three to four feet, into a massive and compact phosphate rock, which is similar in appearance to the phosphatic fragments in the bed described above, except that it is in a solid mass, and is probably the ledge whence the fragments were derived. The surface of the spongy, calcareous rock is very uneven and has been much eroded (Fig. 31). It seems as if Rocky Hill, when submerged, was much worn before the pebbles and the sand were deposited on top of it.

AMORPHOUS NODULAR PHOSPHATE DEPOSITS OF NORTH WALES.

The rock phosphate deposits of North Wales belong to the Caradoc and Bala group of the Cambro-Silurian or Lower Silurian formation. They immediately overlie the Bala limestone beds and are overlaid by fossiliferous shales, sometimes more or less calcareous. They belong to the class of rock phosphates, or phosphates having no definite chemical composition, and are remarkable as being, geologically, the oldest of the commercially important phosphate beds which still preserve the remains of organic life.

The phosphate bed has been traced by Mr. D. C. Davies from the town of Llanfyllin to the hills north and west of Dinas Mowddwy.[1] Mr. Davies has calculated that the area already known to contain this bed amounts to almost 140 square miles, and he thinks it will probably be found wherever the Bala limestone occurs.

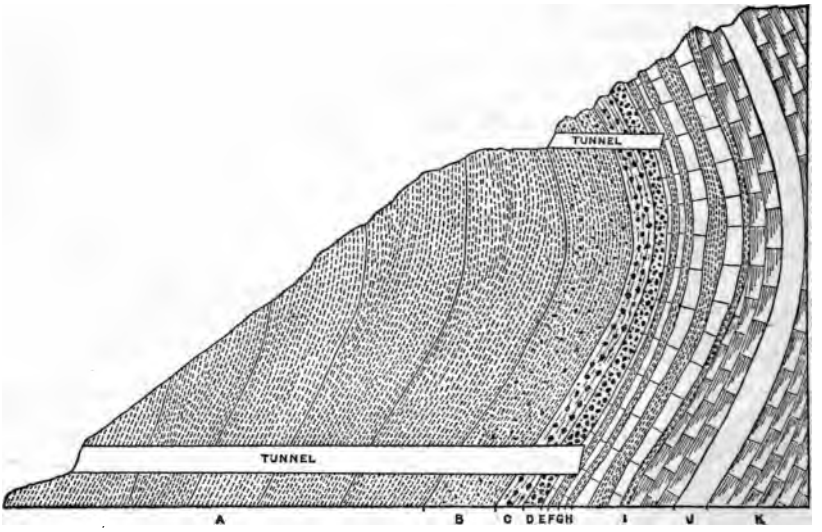


FIG. 32. Section of strata at Cwmgwynen phosphate mine, southwest of Llangynog, North Wales; after D. C. Davies, Quarterly Journal Geological Society of London, 1875. Scale: 1 inch = 80 feet.

As will be seen from the sections (Figs. 32 and 33), the formation in which the phosphate bed occurs has been much twisted and contorted. In fact, the phosphate bed, wherever found, is in an almost vertical position. It varies from ten to fifteen inches in thickness and consists of a mass of black nodules, varying from the size of an egg to that of a cocoanut, "closely packed together and even running into each other." The nodules are cemented into a solid mass by a black matrix, and the whole mass gives an average of 46 per cent. phosphate of lime, while the separate nodules sometimes contain 64 per cent. The bed contains considerable graphite, which gives the black color to both the nodules and the matrix and often gives the former a polished and glossy ap-

[1] Geol. Mag., vol. 2, London, 1875, p. 183.

pearance. There are numerous remains of animal life in the bed, but the whole deposit has been so affected by chemical action that, though the traces of organic forms are left, it is often very difficult to distinguish them. Still Davies[1] has recognized the remains of *Modiola*, *Aviculopecten*, *Orthoceras*, *Orthis*, *Lingula*, and trilobites, besides traces of many other species.

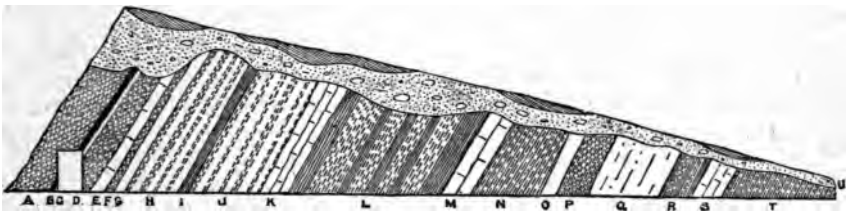


FIG. 33. Section of strata at Berwyn phosphorite mine, west of Llangynog, North Wales; after D C. Davies, Geological Magazine, London, 1875. Scale: 1 inch=32 feet.

M. H. Johnson,[2] who has made numerous sections of the North Wales nodules, has found that many of them contain a species of sponge. He has also found in the nodules fragments of mollusk and crustacean shells, with bodies looking like *Coscinopora*. From these observations he concludes that the nodules are of organic structure. It seems more likely, however, that the nodules resulted from the phosphatization of a calcareous bed, which may have contained the organic remains discovered by Mr. Johnson in the nodules. Davies thinks the bed represents the remains of an old Laminarian zone and that it originated by the phosphatization of calcareous matter by the phosphates from animal matter and seaweed.

The nodules have been so affected by heat and chemical action that they often are found blending and running into each other. They sometimes blend gradually with the matrix, the whole bed assuming a shaly structure, so that it is often impossible to draw a distinct line of division. The mass of the stratum is sometimes found to have a very similar composition over large areas; but where the underlying bed becomes more arenaceous the nodules become much poorer in phosphate and richer in siliceous matter.[3] Thus, at Green Park, the bed averages only 20 per cent. phosphate of lime. The phosphate stratum, in some places, contains numerous concretions and crystals of sulphide of iron, which rust on exposure to the atmosphere, thus changing the color of the bed from black to brown. The phosphate of lime is itself often replaced by these sulphides. Such is the case in many parts of the western outcrop of the bed, especially on the flanks of Mount Aran

[1] Geol. Mag., vol. 4, London, 1867, pp. 251-253.

[2] Ibid., vol. 2, n. s., 1875, p. 238.

[3] This is a strong argument for the theory of the formation of the nodules by the phosphatization of the underlying bed.

Mowddwy. Such large quantities of sulphides and graphite as are found in this phosphate bed, according to Davies, seem to show the former presence of vegetable life.

An examination of the analyses given farther on will show that there is little or no carbonate of lime in these phosphates. Davies, in speaking of this fact, says:[1]

Schmidt found in the inner side of the mouth of *Unio* and *Anodonta* no less than 15 per cent. of phosphate of lime, 3 per cent. of carbonate of lime, and 82 per cent. of organic matter, from which the inference was drawn that the phosphate was separated from the blood by this organ for the purpose of cell formation.[2] The doctor adds: "It seems probable that the carbonate is converted, in the animal, into phosphate by the phosphorus it contains." Here, perhaps, we have a clew to the missing carbonate. The great preponderance of phosphatic organisms, with which the period covered by the deposit commenced, gradually absorbed and secreted all carbonate of lime, whether held in solution in the water or redissolved from the shells of dead mollusks; and so, turning it into phosphate, grew and multiplied exceedingly, and became at last almost sole masters of the position by this appropriation, until the supply of carbonate of lime became insufficient for their sustenance, as the mineral conditions came on under which the overlying shales were deposited.

It seems possible, however, that the absence of carbonate of lime in the Wales phosphate is due to its having been leached out during the process of partial metamorphosis to which the bed has been exposed, as the effect of metamorphosis is often to segregate from the rock which is being acted on the minerals of which it is composed.

The phosphate bed is often separated into two or three smaller beds by thin bands of the underlying limestone. It is always found, however, that when the upper one or two beds, as the case may be, run into the overlying shale they always run out and the lowest bed is always the continuous one.

The bed immediately underlying the phosphate bed is a pure limestone, often covered on the surface with small brachiopods and other fossils. It has an average thickness of 6 inches and contains 15 to 20 per cent. phosphate of lime. Like the phosphate bed, it is very continuous and the two are always found together. It is underlaid by a large series of interstratified shales and more or less fossiliferous limestones. This formation, known as the Bala limestone, gradually runs into the underlying ash beds.

The phosphate bed is overlaid by a series of fossiliferous shales. Those immediately over it have all been phosphatized to a greater or less extent, and the more the phosphatization has gone on the more completely have all traces of organic life been obliterated. In the overlying shale at Cwmgwynen, Davies found remains of *Echinosphærites balticus*, *Caryocystites*, and other echinoderms, *Lingulæ*, *Modiolæ*, *Theca*

[1] Quart. Jour. Geol. Soc. London, 1875, vol. 31, pp. 364.

[2] *Unio* and *Anodonta*, as well as all other species of the suborder to which they belong, are fresh-water forms, while the beds under consideration are certainly of marine origin. It is most likely that the phosphate matter came from brachiopods and trilobites.—N. S. S.

Forbesii, Cycloceras arcuatum, C. Sonax, Orthocerata, Illænus Davisii, and other forms.

The phosphate bed of North Wales was discovered by a miner in 1863, in a ravine near Cwmgwynen, 5 miles from the town of Llanfyllin. At first the nature and value of the bed were unknown, but finally a specimen was sent to Dr. A. Völcker, who analyzed it and made known its importance. Several mines have since been started at Cwmgwynen, Penygarnedd, Berwyn, Llanfyllin, and other places, but none of them has been successful and at present no Welsh phosphate is mined. The reasons for this want of success were the distance of the mines from any railroad or navigable river, the low percentage of phosphoric acid (see analyses), and the depressed state of the phosphate market. Moreover, the bed is expensive to work, as regular mining operations are necessary to win the phosphate; it also often contains considerable iron, which causes superphosphate made from it to have a sticky consistency.

Analyses of North Wales rock phosphates.

[I and II. Analyses of two specimens from Cwmgwynen, by Völcker (Quart. Jour. Geol. Soc. London, 1875).]

	I.	II.
Phosphate of lime	64.16	48.50

"There was no carbonate of lime, some fluoride of calcium, alumina, and oxide of iron.

"The darker-colored contained more graphite and were richer in phosphate of lime than the lighter-colored specimens."

[III. Analyses of nodule from Berwyn mine, North Wales, by D. H. Richards (ibid., vol. 31, pp 364, 365).]

Moisture and organic matter	4.200
Sand	22.600
Tribasic phosphate of lime	64.165
Oxide of iron and alumina	6.890
Other constituents not determined	2.145
	100.000

Another analysis of a similar nodule gave 61.44 per cent. phosphate of lime.

[IV and V. Analyses of Berwyn mine phosphate, North Wales, by F. C. Hills and Co. (ibid., p. 365).]

	IV.	V.
Loss on burning	6.77	3.06
Phosphoric acid (1)	22.54	20.92
Lime	31.08	30.13
Oxide of iron and carbonic acid	19.12	22.88
Insoluble matters	20.49	23.01
Total	100.00	100.00
(1) Equal to tribasic phosphate of lime	49.207	45.67

Five other analyses of the bulk of the deposit, made by Messrs. Hills, gave an average of 46.85 per cent. phosphate of lime. There was also in all the samples about one-half per cent. of copper. Analyses of phosphate from near Llanfyllin, North Wales, gave Messrs. Hills "a range of from 20 to 30 per cent. of phosphate of lime." (Quart. Jour. Geol. Soc. London, 1875, vol. 31, p. 365.)

[VI and VII. Analyses of two samples from northwest of Dinas Mowddwy and Llan-y-Mowddwy, North Wales, by Hills (Quart. Jour. Geol. Soc. London, 1875).]

	VI.	VII.
Phosphate of lime	2.90	1.72
Sulphur	34.38	34.20

The rest was made up of sand, iron, and alumina.

[VIII. Analysis of North Wales phosphatic limestone, by Völcker (Rep. Brit. Assoc. Advanc. Sci., 1865, p. 38).]

Tribasic phosphate of lime	34.92
Oxide of iron	2.34
Alumina	6.52
Carbonate of lime	20.75
Carbonate of magnesia	5.92
Magnesia, in a state of silicate	2.07
Iron pyrites	2.79
Sulphuric acid	0.16
Insoluble siliceous matter	20.95
Organic matter and loss	3.58
	100.00

[IX. Analysis of phosphatic black shale, by Völcker (ibid., p. 38).]

Organic matter and loss	3.98
Lime	37.16
Phosphoric acid	29.67
Equal to tribasic phosphate of lime, 64.16.	
Magnesia	0.14
Oxide of iron	1.07
Alumina	5.84
Matter insoluble in dilute hydrochloric acid	22.14
	100.00

[X. Analysis of phosphatic black shale, by Völcker (ibid., p. 39).]

Tribasic phosphate of lime	52.15
Lime, present as fluoride of calcium and as silicate	4.23
Magnesia	0.32
Alumina	7.71
Oxide of iron	2.01
Sulphuric acid	0.26
Iron pyrites	7.52
Insoluble siliceous matter	22.44
Organic matter and loss	3.36
	100.00

AMORPHOUS NODULAR PHOSPHATE DEPOSITS OF ENGLAND.

Phosphates are found in England, both in the Cretaceous and Tertiary formations. The Cretaceous phosphates are the most important, in both quantity and quality. They occur in two different parts of the Lower Cretaceous, namely, in the Upper and in the Lower Greensand.

Phosphatic beds of Cretaceous Upper Greensand.—The outcrop of the Upper Greensand formation in England begins in the north at Flamborough Head, in Yorkshire, and runs west and southwest for about twenty miles, when it turns abruptly to the southeast and extends continuously in that direction to within three miles of the north coast of the Wash, where it becomes covered with alluvium. It appears again on

the south shore of the Wash at St. Edmunds and runs south by southwest to Downham Market. Here it becomes covered with alluvium and does not appear again for about twenty-three miles, when it crops out three miles below Cambridge, on the Cam. From Cambridge it runs in a southwesterly direction through the counties of Cambridge, Bedford, Buckingham, Oxford, Berks, Wilts, and Dorset, and reaches the southern coast at Lyme Regis and Sidmouth. On the southern coast of Dorsetshire there are numerous outcrops of Upper Greensand, as well as on the Isle of Wight. In the southeast of England there is also a very considerable Greensand outcrop. It commences near Beachy Head, in Sussex, and runs west by a little north to Petersfield, in the east of Hampshire. Here it turns abruptly to the north and runs in this direction to Alton and Farnham, in Hampshire and Surrey, respectively. Thence it takes another abrupt turn to the east, and runs in a general easterly direction until it comes to the coast again, at Folkestone in Kent.

The Lower Greensand is not so continuous as the upper, but it occurs at intervals along most of the outcrops mentioned above, and in Sussex and Kent it is the uninterrupted accompaniment of the Upper Greensand. In Yorkshire it runs from Flamborough Head west for about fifteen miles. It crops out again with the Upper Greensand about three miles south of Barton and runs continuously to Burgh. Again it crops out near Cambridge, and extends thence to Buzzard in Bedford. From there on, in a southwest direction, it occurs in small outcrops along the line of the Upper Greensand In the Isle of Wight there are large outcrops of it. This same Greensand belt can be traced across the English Channel to the Continent. In the Brunswick and Hartz districts, at Goslar, Schoeppenstedt, and Salzgitter, the same nodules and shell casts are found as in the Lower Greensand in Cambridgeshire and Bedfordshire. But, though the belt is thus seen to have a very wide extent, the conditions which are necessary for the profitable working of a phosphate deposit are so many and so rarely satisfied that the phosphatic beds have been mined in very few places throughout this many hundred miles of outcrop. On the Continent the bed has been worked to no considerable extent.

The relative positions of the Upper and Lower Greensand formations is best shown by a section. The following one is given by Messrs. Paine and Way.[1]

The Cretaceous formation of England is divided into the Chalk and the Greensand. These again are subdivided as follows:

Chalk	1. Soft, white chalk with flints. 2. Hard, white chalk with few or no flints. 3. Chalk marl.
Greensand	1. Upper Greensand and firestone rock. 2. Gault, or blue marl. 3. Lower Greensand, made of iron sand and occasional limestone beds.

[1] Jour. Royal Agric. Soc., vol. 9, 1848.

The first two beds of the chalk are very poor in phosphoric acid, rarely containing over twelve-one-hundredths of 1 per cent., but the underlying marl is much richer and sometimes contains almost 2 per cent. of phosphoric acid. The marl is of a grayish color and contains specks of Greensand, which become more and more numerous until the marl gradually merges into the underlying Greensand bed containing the phosphatic nodules. The passage from the Upper Greensand to the Gault is often very abrupt, especially in Cambridgeshire and Bedfordshire, where the nodule bed often lies on the eroded surface of the Gault. The Lower Cretaceous deposits of Cambridgeshire and Bedfordshire differ from those of the south and west of England in the fact that the former lack that great thickness of Upper Greensand which exists in the southern counties. At the same time the lower beds of the Chalk are the same in both areas. In Hampshire and Dorsetshire there is a thin stratum, similar to the Cambridge nodule beds, which, like it, passes up gradually into the Chalk marl. But the difference is that in the case of the southern counties the arenaceous deposit, which sometimes reaches the thickness of many feet, comes between the phosphate bed and the Gault, while in the case of the Cambridge and Bedford deposits the nodule bed, which rarely exceeds one foot in thickness, rests immediately on the Gault. Concerning the absence of this arenaceous deposit in Cambridgeshire, Mr. O. Fisher[1] says: "It is probably due to the ridge of old rocks beneath the London area, which shut off the early Cretaceous sea, to the north of it, from those southwestern lands which yielded the sandy spoils." He also suspects a similar cause to have "produced the marked change between the Lower Cretaceous rocks in Cambridgeshire and the corresponding beds in Norfolk and Lincolnshire." Mr. Seeley[2] thinks that this increased thickness of Greensand to the south and southwest is due partly to the shelving of the sea bottom towards the south and partly to a current piling it up in the hollow, but principally because the southern area was nearer to the old plutonic rocks, whence, he thinks, the necessary ingredients of the Greensand came.

The principal phosphate diggings have been in the Upper Greensand of Cambridgeshire and Bedfordshire. The nodules in this deposit are buried in the Greensand, which varies from one inch to a foot in thickness and which is all that is left in these districts to represent the immense thickness of Greensand in the southern counties. In fact, it is a matter of serious doubt with some geologists whether the two deposits really represent one and the same geologic horizon.

The matrix of the nodules is not pure Greensand, but is composed partly of siliceous and calcareous matter and partly of glauconitic and phosphatic grains. The siliceous matter consists mostly of colored

[1] Quart. Jour. Geol. Soc. London, vol. 29, 1873, p. 62.
[2] Geol. Mag., vol. 3, London, 1866.

quartz, obsidian, and grit. The calcareous matter is composed mostly of sponge-spicules, spines and plates of echinoderms, minute shells, polyzoa, bivalve entomostracá, microscopic corals, foraminifers, and calcareous concretions.[1] There are also in the bed "lumps of Chalk marl[2] which have fewer green grains in them than the matrix in which they are embedded." From this and other facts Mr. Fisher concludes that these phosphate beds seem to have been washed out of a calcareous marl, similar in character to the marl which lies above it. In short, he continues, the nodule bed is a condensation of the "Chalk marl with glauconite grains." On the other hand, Mr. Sollas thinks that the nodule bed has been derived from the destruction of the underlying Gault. The Gault contains nodules and fossils, but not nearly so many as the overlying bed. Mr. Fisher urges against this hypothesis that the nodules of the Gault are smaller and of a lighter color than those of the nodule bed proper. Though the nodules are of a lighter color on the surface, the interior is of a color very similar to that of the Greensand nodules. Mr. Sollas shows that by the action of hydrochloric acid the Greensand nodules assume this same color on the surface, and consequently it is possible that the Gault nodules may have been acted on by water, acidulated by some acid or acid salt, percolating through the bed, and thus had their surfaces bleached.

The phosphatic part of the nodule bed consists of shell casts, fossils, and nodules. There are numerous species of *Rhabdospongia*, *Bonneyia*, *Acanthophora*, *Polycantha*, *Retis*, and *Hylospongia*, besides many other Cretaceous forms. The nodules and casts are of a black or dark-brown color and have a very variable specific gravity and hardness.

Many of them are worn, broken, and rounded, showing them to be clearly derivative masses, while others are perfect in shape and show no signs of having been removed from their original bed.[3] The derivative fossils and nodules are covered with *Plicatulæ*, and the smooth, broken surfaces of many of them, which are coated in this way, show, as Mr. Fisher thinks, that they must have been phosphatized before being deposited in their present bed, and he thinks that the phosphate was concentrated from a carbonic acid solution by animal matter. Besides the shell casts and fossils, there are two distinct varieties of nodules proper. The first is a reddish-brown and utterly shapeless variety. It is very soft when freshly dug, never becoming harder than ordinary chalk.[4] It has a very light specific gravity and is invariably rich in phosphoric acid.[5] A second variety is much more plentiful than the last. It consists of a dark-brown mass of a very variable shape. It is hard and heavy. It varies from pieces of micro-

[1] W. J. Sollas: Quart. Jour. Geol. Soc. London, vol. 28, 1872, p. 398.
[2] O. Fisher: ibid., vol. 29, 1873, p. 53.
[3] O. Fisher: ibid.
[4] Paine and Way: Jour. Royal Agric. Soc., 1848.
[5] See analyses.

scopic smallness to masses weighing four pounds. It occurs adhering to the surfaces of *Syphonæ*, corals, and shells, and appears to have once been in a plastic state. This substance has been called by Dr. G. A. Mantell[1] "molluskite," and he considers it the remains of the soft parts of mollusks. In describing it he says:

This substance is of a dark-brown or black color, and occurs either in shapeless masses, which are irregularly distributed among the shells and other organic remains, in sandstone, limestone, etc., or as casts of shells, or occupying their cavities. * * * Upon analysis this substance is found to contain a large proportion of animal carbon. The rocks of firestone at Southbourne, on the Sussex coast, are mottled with brown molluskite and hard amorphous concretions, consisting of carbon and phosphate of lime, mixed with sand and other extraneous matter. Casts of shells of the genera *Venus* and *Arca*, etc., entirely composed of the same kind of materials, are also abundant in those rocks. * * * The gelatinous bodies of the *Trigoniæ*, *Ostreæ*, *Rostellariæ*, *Terebratulæ*, etc., detached from their shells, may have been intermingled with the drifted wood in a sand-bank; while in some instances the animal matter would remain in the shells, be converted into molluskite, and retain the form of the original.

Both Mr. Fisher[2] and Mr. Sollas,[2] who have spent considerable time in studying the nodule bed of the Upper Greensand, concur in the belief that the nodules are not of either concretionary or coprolitic origin, but are composed of phosphatized animal matter. In this belief they agree with the theory of Dr. Mantell in its most important point.

Many of the nodules are traversed by shrinkage cracks and wrinkles and have a peculiar granulated surface like that of leather. Mr. O. Fisher says:

On the whole a microscopical examination of these bodies rather recalls me, so far, to my original opinion that they were sponges, while at the same time it must be admitted that in their external appearance they much resemble *Alcyonaria*.

It is often found that the nodules are richer in their exterior part than in the interior. Thus Professor Way found the following results in analyzing different parts of a spongoid body:[3]

Exterior	32.27 per cent. phosphate of lime. 61.71 per cent. carbonate of lime.
Intermediate	13.87 per cent. phosphate of lime. 67.14 per cent. carbonate of lime.
Interior	10.26 per cent. phosphate of lime. 67.17 per cent. carbonate of lime.

Such results have been found to hold true with many other phosphates and show, beyond a doubt, that the phosphatization went on from the outside towards the interior. As regards the internal structure of some of these nodules, Mr. Sollas says:[4]

Thin sections examined under the microscope vary from colorless to yellowish brown when transparent, but sometimes they are almost opaque from included earthy

[1] Medals of Creation, vol. 1, p. 432.
[2] Quart. Jour. Geol. Soc., vol. 29, London, 1873.
[3] Jour. Roy. Agric. Soc., 1848.
[4] Quart. Jour. Geol. Soc., vol. 29, London, 1873.

matter. Granular patches of a deep-red color are sometimes scattered throughout the lighter-colored portions. Spicules occur in many sections, presenting some of the most characteristic forms of sponge-spicules; as, for example, hexaradiate, triradiate, hamate, sinuate, and connecting forms. These spicules are frequently grouped together in a manner which seems to indicate that they cannot have been washed in from the sea bed during fossilization. Globular bodies $\frac{1}{400}$ inch in diameter are numerous; they seem to be gemmules. *Polycistina* and *Xanthidia* occur in some sections. With polarized light the sections appear distinctly cryptocrystalline, presenting an appearance very nearly resembling that of chalk flints when examined in the same way. A very curious phenomenon may be alluded to here. A number of small circles may be seen in some sections, each of which is marked by a black cross, the arms of which radiate from the center to the circumference. On turning the analyzer the cross revolves and, when the analyzer has been turned round 90°, is replaced by a complementarily illuminated cross. The explanation of these appearances seems to be as follows: Small *Globigerina* shells and other similar spaces occur in the nodules, into which the crystalline apatite, which was diffused throughout the fossil, has penetrated and crystallized inwards from their walls to their centers, thus forming a radiating mass of crystals. It is well known that crystals arranged in this way will produce the phenomena described.

Mr. Sollas[1] thinks that many of the nodules of the Upper Greensand are phosphatized sponges. Others he considers to be "phosphatized animal matter decomposed so far as to have lost all traces of its original structure before mineralization." He found fish scales and bones in many of these nodules, and therefore concludes that the animal matter was sometimes derived from small fish. He does not seem to take into consideration that the scales and bones may have been buried in a matrix of calcareous matter, and that this substance, whether it was marl or limestone, may have been phosphatized, thus forming phosphatic masses, which, of course, would contain the same fossils as the original calcareous substance from which they were formed.

The phosphate bed of the Upper Greensand varies considerably, not only in the quantity of phosphatic nodules, but also in the chemical composition of the individual nodules. It is often found that two places may be equally rich in the quantity of nodules, while the content of phosphoric acid in them may be widely different.

All through the counties of Dorset, Somerset, Wilts, and Devon the nodules are very much more siliceous and less abundant than the nodules of Cambridgeshire and Bedfordshire.[2] Besides the variability in the phosphatic richness of the bed, it is also sometimes very variable in its mode of occurrence. At times it will cover many square miles continuously, while at others it occurs in pockets in the surface of the Gault. At other times, according to Mr. Fisher, the bed shows signs of contortion, as indicated in Fig. 34. It will be seen, by examining the analyses given beyond, that the Greensand matrix of the phosphatic nodules varies also very much in its content of phosphoric acid. The

[1] Quart. Jour. Geol. Soc., vol. 28, 1872, p. 398.
[2] L. Jenyns: Geol. Mag., London, 1866.

amount varies from 2 to 10 per cent., and is probably due to small grains of phosphatic matter in it.

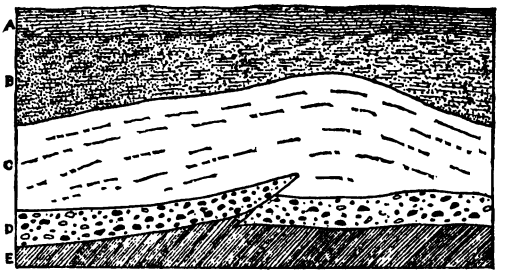


FIG. 34. Distorted bed in Cambridgeshire, England; after O. Fisher: Geological Magazine, London, 1871. A, shelly soil; B, clay or clayey gravel; C, white clay; D, phosphate nodule bed; E, Gault.

Phosphatic beds of Cretaceous Lower Greensand.—These beds occur between the Coral Rag formation at the base and the Gault on the top. Their position with regard to these formations will be best seen in Fig. 35, section at Upware, Cambridgeshire.[1] The Coral Rag is a coralline rock varying much in texture, sometimes loose and porous, and at others compact and oölitic or arenaceous. Upon this the Kimmeridge Clays rest, probably conformably.[2] But at some places, as at Upware, the Kimmeridge Clay has been washed off the Coral Rag, which, in such cases, often comes into direct contact with the overlying nodule bed. Sometimes, as a result of this destruction, there is a deposit of fragments of Coral Rag and Kimmeridge Clay immediately overlying the Coral Rag formation.

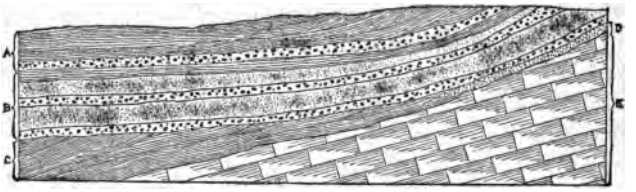


FIG. 35. Section at Upware, Cambridgeshire; after W. Keeping. A, Gault and phosphatic nodule beds; B, clay, sand, and nodule beds; C, Kimmeridge Clay and Coral Rag; D, junction bed.

Next in an ascending series comes the "lower phosphate bed." Mr. Keeping considers this as the first definite bed of the Upware Neocomian. It consists of a mass, indiscriminately mixed together, of phosphatic nodules and shell casts, fossils, pebbles of quartz, flint, Lydian stone, and jasper, besides occasionally a fragment of Coral Rag. They are all more or less rounded and worn, though some of them still preserve their angular shape. The stones and nodules vary from one-

[1] The Fossils and Palæontological Affinities of the Neocomian Deposits of Upware and Brickhill, by Walter Keeping, p. 4.

[2] Ibid., p. 3.

sixteenth to an inch in diameter and are embedded in a sandy matrix. Very often the mass has been cemented together by calcareous matter, forming irregular patches of conglomerate. There also occur in this bed many delicate and beautiful shells of mollusca, which are not at all worn, but preserve their most delicate parts intact. Lamellibranchs and gasteropods are numerous.

Above this bed comes a bed of sand composed largely of grains of ironstone, quartz, chert, and Lydian stone. Near the overlying and underlying beds there are irregular masses of slightly phosphatic sandstone.

Next above this sand bed comes the "upper phosphate bed." It resembles the "lower phosphate bed" in most respects, except that its nodules are of a lighter color, and the bed is not cemented by carbonate of lime, so that it has nowhere been indurated into a conglomerate. The siliceous pebbles are the same.

Overlying this is another bed of sand very similar to the lower sand bed.

Above this comes a clay bed. It has been referred to the Gault, but Messrs. Keeping and Bonney think that it is probably the representative of a bed of sandy clay belonging to the Lower Greensand. This is thought more likely, because phosphatic nodule beds, especially in the Cretaceous formation, usually occupy the lines of chronological breaks.

The overlying bed is another bed of phosphatic nodules. It contains many fossils and is very similar to the two nodule beds already described. This bed is overlaid by the Gault formation.

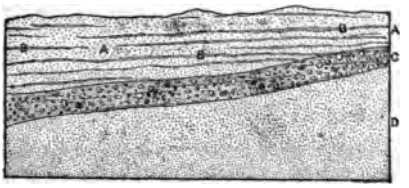


FIG. 36. Section at Sandy, Bedfordshire, England, after J. F. Walker. A, sand; B, oxide of iron C, conglomerate; D, sand.

Sometimes the three phosphate beds mentioned above seem to combine into one (Fig 36). Sometimes, also, the lower bed is not cemented, but is loose and sandy, just like the upper beds. The following sections will show the variations in the upper Neocomian deposits:

Section by W. Keeping and E. B. Tawney, at Spinney Abbey.

		Ft.	In.
A	1. Brown surface earth	1	6
	2. Head of blue clay	0	9
	3. Irregular gravelly zone, the pebbles being mostly flints and coprolites, about	0	3

		Ft.	In.
	4. Blue, yellow, and coarsely mottled plastic clay, with scattered coarse quartz and other sand grains and numerous sandy concretions	2	0
	5. The "silt bed," a chocolate-brown and yellowish sand, passing into a sandy clay, which is rather coarse, loose, and like an ordinary shore sand. It consists principally of quartz and iron grains. This bed passes gradually into bed 4	2	0
B	6. The "upper coprolite seam," a pebble bed of phosphatic nodules, Lydian stone, chert, quartz, and other pebbles as big as beans packed in loose, iron-colored sand. Some irony concretions occur in its upper part, where it passes into bed 3	2	0
	7. The "lower coprolite seam," a thin band where the coprolites are darker and better than in the upper seam. The sandy matrix is hardened almost to a rock by carbonate of lime, which was probably derived from the underlying bed (*a*)	0	3
C	A calcareous grit of coralline age. It is a hard, gritty, bedded limestone, gray colored, with scattered large oölitic grains; no fossils seen		

In the last section the nodules are darkest near the base. The phosphatic and siliceous pebbles are in about equal quantities. Silicified wood, ferruginous concretions, and hard lumps of clay are numerous. The nodules contain more alumina than those of the Upper Greensand (Walker).

The nodules proper of the phosphate beds are of a very variable character, in which respect they resemble the nodules of North and South Carolina. They vary in size from pieces no larger than a grain of sand to masses weighing 3 or 4 pounds. They give off an organic smell when rubbed, have a cubic fracture, and vary from yellow to chocolate brown in color. Their hardness is 3 to 4. The darker nodules are near the bottom of the bed; though, in most cases, the color depends on the substance originally phosphatized (Keeping). The nodules sometimes are of a perfectly homogeneous and opal-like nature. From this they go through all stages of sandiness, till they are simply nodules of phosphatic sandstone. Keeping, in describing them, says:

> There are certain curious branching, interlacing, undulating, or simply straight-crossing structures forming little gutters over the surface of the nodule, and canals penetrating into its substance. * * * Some of these are mere shrinkage cracks and others are the marks of where "episites," such as *Serpulæ* and *Polyzoa*, have been attached to the inner surface of the original shell; others again are probably the work of boring creatures, especially sponges, but the great variety and many peculiarities of type that occur and their constant association with phosphatic nodules are facts not sufficiently explained by the accumulated work of all the above-mentioned agents.[1]

These nodules are not so rich in phosphate of lime as those of the Upper Greensand; they average 40 to 50 per cent. (Völcker), while those above the Gault average 50 to 60 per cent., phosphate of lime (Way). (See analyses.)

[1] This exactly describes the surface of many of the phosphatic nodules of the Alabama Cretaceous formation.

Most of the fossils in these Lower Greensand phosphate beds have been derived from older formations. They are rolled and worn to such an extent that it is frequently impossible to identify them. Keeping, in speaking of the piles of phosphatic material at the mines, says, that "the coprolite heap looks like one mass of *Ammonites biplex*, mostly worn and fragmentary." The fossils are mostly worn species of mollusca of Oxfordian, Kimmeridgean, or Portlandian species of the Upper Jurassic (W. Keeping). Many of the derived species are of the Neocomian age, such as *Ammonites Deshayesii*, *Ancyloceras* sp., *Hamites* sp., *Thetis minor* Sowerby, *Terebratula ovoides* Sowerby, and other forms.

Thus it will be seen that these latter fossils have been derived from a bed but very little older than the nodule bed, as this latter deposit belongs, according to J. F. Walker,[1] to the Upper Neocomian formation. Mr. Walker[2] also thinks that a large number of the derived fossils came from the underlying Kimmeridge Clay. Many of the fossils of the Upware nodule bed are preserved in amorphous or crystalline calcite, others in ferruginous sandstone and phosphate of lime. The fossil wood is silicified. According to W. Keeping, all the shell casts and fossils that have been mineralized by phosphate or limonite are derived fossils and belong mostly to Jurassic species. They are easily recognized by their rolled and water-worn condition. Walker divides the fossils into (*a*) indigenous fauna, preserved in oxide of iron, and (*b*) derived fossils, preserved in phosphate of lime. H. G. Seeley, on the other hand, thinks that all these fossils are natives of the beds in which they are found.

As regards the mode of phosphatization of these beds, Walker, Keeping, Teall, and others agree in the theory that it is the result of the soaking of calcareous substances in decomposed animal and vegetable matter. The Coral Rag fragments in the bed are not at all phosphatized. In this particular the deposit resembles those of Alabama and the Carolinas, where shells perfectly free from phosphatic matter are associated with beds of highly phosphatic nodules and fossils. This would seem to show that the non-phosphatic substances were deposited after the nodules had been phosphatized. But Dr. C. U. Shepard, jr.,[3] and W. Keeping explain the phenomenon by supposing that the purer forms of carbonate of lime are not so susceptible to phosphatization as the impure forms.

A very distinctive feature between the Upper and Lower Greensand phosphate deposits is the nature of the matrix of the nodules in the two formations. As has been already said, the matrix of the Upper Greensand is a calcareous Greensand containing 2 to 10 per cent. of phosphoric acid, while the matrix of the Lower Greensand nodule beds

[1] Mon. Fossil Trigoniæ, Pubs. Palæontographical Soc., vol. 29, 1875, p. 145.

[2] Annals Mag. Nat. Hist., 1866.

[3] South Carolina Phosphates.

is a highly siliceous sand, containing no phosphate, except where the nodules have been decomposed. The siliceous pebbles of these lower beds are of very general distribution. They are found all along the Lower Greensand outcrop in England at Upware, Sutton, Brickhill, Farrington, and other places, also in the Neocomian strata at Schöppenstedt, in Brunswick. Many of these pebbles are fossiliferous.

Mr. Keeping[1] found in some chert pebbles many shells and crinoids of the Carboniferous age. In others he found many Jurassic shells and echinoderms. He thinks most of the pebbles were derived from an ancient barrier axis, which, in the Lower Neocomian period, separated the north from the south Neocomian seas in Europe, but "which was in the time of the deposition of the iron sand series suffering rapid denudation and destruction."

The Lower Greensand phosphate beds have numerous outcrops in Surrey, Sussex, and Kent. They are, however, thought by W. Keeping not to be of the same age as the beds of Cambridge and Bedford, but to belong to the Sandgate and Hythe series.

Tertiary phosphate beds.—The Tertiary phosphate deposits occur in or directly under the various Crag formations of Norfolk, Suffolk, and Essex, but are richest and most extensive in the county of Suffolk. The Crag of Suffolk and Norfolk runs along the coast from about 5 miles northwest of Kromer, in Norfolk, for a distance of 70 to 80 miles to Hardwick, in the northern part of Essex. This belt is from 7 to 22 miles wide, being widest in the neighborhood of Norwich and narrowest at Halesworth, in Suffolk. Beyond these limits the Crag often occurs in patches in the county of Essex. The Suffolk and Norfolk Crag does not extend all over the above mentioned area, but in many places it is covered by alluvium, and in others, especially in Essex and in the south of Suffolk, it has been removed by erosion, and the London clay crops out.

It is in the county of Suffolk, and especially in the district between the rivers Orwell, Deben, and Alde, and in the country surrounding the central mass of Coralline Crag at Sutton, that the Tertiary phosphate beds have been most successfully and profitably worked. The Crag formation of this country is composed largely of the Coralline and Red Crags. These formations are each separable into two divisions. Prof. J. Prestwich[2] has divided the Coralline Crag into the upper part, consisting mostly of remains of Bryozoa, and the lower part, consisting of light-colored sand with many shells mixed in with it. The two beds together are rarely over 20 feet thick, and rest on the London Clay (Eocene). The Red Crag consists of irregularly stratified sands stained with oxide of iron. It comes above the Coralline Crag, though in most

[1] The Fossils and Palæontological Affinities of the Neocomian Deposits of Upware and Brickhill, 1883.

[2] Quart. Jour. Geol. Soc. London, vol. 27, 1871.

cases it rests directly on the London Clay, the Coralline Crag having been eroded. The two divisions of the Red Crag are often very difficult to distinguish. The only difference is that the lower division usually has more shells scattered through it. According to Professor Prestwich, the lower division includes all the beds going under the name of red and Norwich Crag, while the upper division includes the Chillesford sands and clays. Both the Coralline and the Red Crags belong to the Upper Pliocene period and are of the same age as the Upper Antwerp Crag.[1]

The phosphate beds occur at the base of the Coralline and Red Crags and immediately over the London Clay. The bed sometimes thins out, and at other times it separates into two seams, divided only by a few feet of shelly crag. Occasionally, also, nodules, and seams of nodules, are found running through all parts of the Red Crag, though the bed at its base is generally the largest and most continuous. The phosphate bed consists of a mass of phosphatic nodules and shell casts, siliceous pebbles, teeth of cetacea and sharks, and many mammal bones, besides occasional fragments of Lower Greensand chert, granite, and chalk flints. There are numerous fossils and shells, *Cardium edule*, *Pectunculus glycymeris*, *Cyprina islandica*, and other forms. The bed varies from 2 to 18 inches in thickness. The nodules vary considerably in both quality and quantity. They are at times of a compact and brittle nature, while at others they are tough and siliceous. They average about 53 per cent. phosphate of lime and 13 per cent. phosphate of iron. The quantity of bones in the beds also varies very much. Sometimes there are few and at other times there are great quantities of mastodon and rhinoceros teeth and bones of other mammals, similar in some respects to those at Eppelsheim in Germany.[2] Large cetacean bones and teeth of Charcharodon and Oxychina are also found. There is considerable dispute concerning the origin of the fossils and nodules in the phosphate beds of the Crag. That most of them are derived masses is shown by their worn and rounded condition. Mr. Jenyns[3] believes that they have come from the London Clay, and in support of this view he calls attention to the similarity of the nodules of the two formations. Professor Prestwich[4] thinks that most, if not all, of the nodules of the Red Crag came from the Coralline Crag.

The phosphate deposits of Norfolk are few and scattered. Most of the phosphatic material from this county is in the form of mastodon, elephant, and rhinoceros bones from the forest and elephant beds. None of the Crag phosphate beds have proved so valuable as the Cretaceous beds. The nodules are harder and more siliceous, making them more difficult to grind and less valuable as a soil stimulant when in the un-

[1] Geol. Mag., London, 1865.
[2] E. Ray Lankester: ibid.
[3] Ibid., vol. 3, 1866.
[4] Quart. Jour. Geol. Soc. London, vol. 27, 1871.

acidulated state. Besides this, they contain considerable phosphate of iron, which causes a superphosphate, made from such nodules, to have a sticky consistency and to be very liable to "revert" to an insoluble condition.

The Crag nodules resemble those of the Cretaceous formation, as well as some of those of South Carolina, in the fact that the exterior part often contains more phosphoric acid than the interior. The following analyses by T. J. Herapath[1] illustrate this fact:

	Exterior.	Interior.
1	1.105 per cent. fluoride of lime.	0.611 per cent. fluoride of lime.
	40.019 per cent. phosphoric acid.	34.015 per cent. phosphoric acid.
2	3.996 per cent. fluoride of lime.	1.961 per cent. fluoride of lime.
	32.043 per cent. phosphoric acid.	21.046 per cent. phosphoric acid.

History of the rock phosphates of England.—The Greensand of England has been used as a fertilizer for many generations. As early as 1790 it was considered so valuable as a soil stimulant that it was carried in carts, sometimes for many miles, all over the counties of Essex and Kent. Immense pits, dug in the Greensand marl, concerning which there is no historic record and which are now overgrown by large oaks and other forest trees, bear witness to the great value placed on this marl in by-gone times. A remarkable example is seen at Worldham, where there is a large excavation 15 feet deep, from which, once, thousands of tons of greensand were removed. But the heaps of phosphatic nodules which are often found near these pits, and which seem to have been thrown away as worthless, show that the value of this part of the bed was not known.

It was not until nearly the middle of this century that the agricultural value of these nodules was appreciated. Doctors Mantel, Buckland, and Fitton, in the early part of the century, pointed out the existence of beds of nodules and fossils in the Cretaceous and Tertiary formations of England, but simply spoke of them as remarkable beds of fossils and nodules. Mr. Berthier, in 1820, also made analyses of similar nodules found in France. But their use as a plant food was not recognized until Professor Henslow made a study of the Red Crag nodules at Felixtow in 1842, and suggested their use in agriculture before the British Association in 1845. It was at this time that the name coprolite, or fossil dung, was first given to these nodules by Professor Henslow. At a later date he saw his mistake in believing the phosphatic masses to be of coprolitic origin, and considerably modified his views. It was certainly a most unfortunate name, as it has since been shown that real fossil dung is a thing of very rare occurrence, and hence the name coprolite, as applied to beds of nodular phosphates, is misleading.

Among the most active of the early advocates of English phosphates

[1]Jour. Royal Agric. Soc., 1851.

were J. M. Paine and J. T. Way,[1] who analyzed many specimens of the material and made many practical experiments, which went far to open up the phosphate mining industry in England. From that time on the use of the English phosphatic nodules became more and more extensive, until within the last few years the immense exports of phosphate of lime from South Carolina, the West Indies, and other localities have thrown so much of that material on the market that the English deposits have become a source of minor importance.

The principal mining operations are carried on in the counties of Cambridge, Bedford, and Suffolk. According to O. Fisher,[2] writing in 1873, the miners in Cambridge had to pay $700 per acre for the right to dig phosphate and had to return the land to its original level condition and resoil it. With all this expense the average yield was only 300 tons per acre, which sold at $12 a ton; while in the South Carolina diggings the yield is 300 to 1,500 tons per acre and it sold, at that time, for $9 a ton. The nodules in England were dug to the depth of 20 feet, but it did not pay to go any deeper.

Dr. C. U. Shepard, jr., informs me that he visited the diggings at Whaddon, near Rowsley, in 1875. They were then working at the depth of 8 to 18 feet, all the surface beds having been exhausted. Sums from $500 to $1,250 per acre were paid for the right to take the rock, and the yields per acre were from 150 to 400 tons. The mining was done in open trenches. The phosphate rock was washed in circular horizontal tubes and was kept moving by rakes worked by steam. The capacity was about 5 tons daily, and the cost of washing about 85 cents a ton. Wages were $6 a week. The nodules were sun-dried and then carted to the railroad for 50 cents per ton.

The production for the three counties of Bedford, Cambridge, and Suffolk from 1875 to 1881 is given as follows:[3]

	Tons.
1875	250,000
1876	258,000
1877	69,000
1878	54,000
1879	34,000
1880	30,000
1881	31,500

Analyses of the amorphous nodular phosphates of England.

[I. "Molluskite," from the Upper Greensand, by M. Berthier.]

Phosphate of lime	57.00
Carbonate of lime	7.00
Carbonate of Magnesia	2.00
Silicate of iron and alumina	25.00
Water and bituminous matter	7.00
	98.00

[1] Jour. Royal Agric. Soc., 1848.

[2] Quart. Jour. Geol. Soc. London, vol. 29, 1873.

[3] Mineral Statistics of the United Kingdom, by Robert Hunt, F. R. S. (From D. C. Davies, Earthy and Mineral Mining, London, 1884.)

[II. Phosphate from the Upper Greensand, at Dippen Hall (Way).]

Insoluble siliceous matter	9.84
Soluble silica	2.36
Phosphoric acid	27.60
Equal to bone earth phosphate, 59.60.	
Carbonic acid	6.96
Lime	44.56
Magnesia and loss	0.81
Oxide of iron and alumina	4.61
Organic matter	3.26
	100.00

[III. Fossil sponge, a branching Alcyonite from the Upper Greensand (Way).]

Insoluble siliceous matter and soluble silica	7.68
Phosphoric acid	29.87
Equal to bone earth phosphate, 61.30.	
Carbonic acid	8.77
Lime	42.29
Oxide of iron and alumina	6.87
Water, organic matter, fluorine and loss	4.52
	100.00

[IV. Red nodule from the Upper Greensand, at Dippen Hall (Way).]

Insoluble siliceous matter, with a little clay	7.18
Soluble silica	3.28
Organic matter	2.49
Phosphoric acid	27.13
Equal to bone earth phosphate, 55.96.	
Carbonic acid	8.77
Lime	39.85
Magnesia	0.96
Oxide of iron and alumina	10.60
Fluorine	Trace
	100.26

[V. Phosphatic nodules from the Upper Greensand (Völcker).]

Moisture and organic matter	4.68
Lime	43.21
Magnesia	1.12
Oxide of iron	2.46
Alumina	1.36
Phosphoric acid	25.29
Carbonic acid	6.66
Sulphuric acid	0.76
Chloride of sodium	0.09
Potash	0.32
Soda	0.50
Insoluble siliceous matter	8.64
Fluoride and loss	4.96
	100.05

[VI. Upper Greensand from Dippen Hall (Way).]

	Coarse part.	Fine part.
Insoluble siliceous matter	21.85	26.25
Soluble silica	20.18	18.11
Organic matter	6.25	5.95
Phosphoric acid	7.80	10.38
Carbonic acid	10.91	10.34
Lime	20.58	19.87
Magnesia	1.59	0.87
Oxide of iron and alumina	8.18	6.18
Potash and soda, not estimated		
	97.34	97.95

[VII. Upper Greensand from Dippen Hall (Way).]

	Coarse part.	Fine part.
Insoluble siliceous matter	26.83	32.81
Soluble silica	26.30	29.14
Organic matter	2.64	3.02
Phosphoric acid (1)	9.31	6.61
Carbonic acid	2.35	2.30
Lime	15.24	9.53
Magnesia	1.43	1.97
Oxide of iron and alumina	13.11	11.46
Potash	Not est.	3.10
Soda	Not est.	0.00
		99.94
(1) Equal to bone earth phosphate	19.22	
(1) Equivalent of earthy bone		13.63

[VIII. Cambridgeshire glauconite (Professor Liveing).]

Water	10.80
Silica	51.09
Alumina	9.00
Iron (protoxide)	19.54
Magnesia	3.37
Lime	0.30
Soda	3.56
Potash	2.47
	100.13

[IX. Phosphate nodules from Lower Greensand (Way).]

Insoluble siliceous matter	43.87
Soluble silica	3.25
Organic matter, water, and fluorine	3.44
Phosphoric acid	20.80
Equal to bone earth phosphate, 42.48.	
Carbonate of lime	1.06
Lime in combination with phosphoric acid	23.86
Oxide of iron and alumina	3.35
Magnesia and loss	0.37
	100.00

[X. Phosphatic nodule from Lower Greensand (Way).]

Silica and sand	13.64
Sulphate of lime	50.16
Water in combination	14.97
Water (accidental)	7.47
Phosphoric acid	4.80
Lime, additional	0.27
Oxide of iron and alumina	8.82
	100.13

From the above analysis it will be seen that most of the phosphoric acid must have been in combination with iron and alumina.

[XI. Large green grains from a Lower Greensand phosphatic conglomerate (Way).]

Soluble and insoluble siliceous matter	18.53
Water	2.28
Phosphoric acid	20.65
Carbonic acid	4.01
Sulphuric acid	5.13
Lime	34.61
Oxide of iron	7.24
Alumina	0.98
Potash	1.79
Soda	1.87
	97.09

[XII. Lower Greensand nodules (Völcker).]

	Average samples of siftings from layers at 1 and 2 feet.	Washed rock from another place.
Water of combination	5.17	5.67
Phosphoric acid	[1] 22.39	[2] 15.12
Lime	32.73	26.69
Magnesia, alumina, and fluorine (by difference)	6.64	4.51
Carbonic acid	3.06	[2] 2.18
Oxide of iron	[1] 8.08	20.61
Siliceous matter	21.93	25.22
	100.00	100.00

[XIII. Partial analysis of phosphatic conglomerate, Lower Greensand, from Folkstone, by Way].

Insoluble siliceous matter	30.60
Phosphoric acid	7.23
Potash	3.31
Soda	1.02

[XIV. Lower Greensand mass, from which the principal fossils and nodules were picked, by Way.]

Insoluble siliceous matter	75.46
Soluble silica	8.12
Organic matter	2.30
Phosphoric acid	0.64

[1] Phosphate of lime, 48.51; carbonate of lime, 6.95.

[2] Phosphate of lime, 32.76; carbonate of lime, 4.95.

Carbonic acid	5.64
Lime	2.01
Magnesia	0.18
Oxide of iron and alumina	5.59
	99.94

Analyses of crag phosphates.

These average 50 to 60 per cent. phosphate of lime (Way).

[I. Phosphate from the crag at Surrey, by Herapath.]

Water	3.400
Organic matter	Trace
Silica with some silicate of alumina and silica of iron	13.240
Chloride of sodium	Trace
Sulphate of soda	Trace
Carbonate of lime	28.400
Carbonate of magnesia	Trace
Sulphate of lime	0.736
Phosphate of lime (tribasic)	21.880
Phosphate of magnesia	Trace
Perphosphate of iron	24.760
Phosphate of alumina	6.998
Phosphate of manganese	Trace
Fluoride of calcium	Some
Loss	0.586
	100.000

[II. Partial analysis of three Suffolk nodules, by Herapath.]

Earthy and other phosphates	64.056	79.545	67.176
Fluoride of calcium	0.311	2.554	2.768
Nitrogen	Traces	0.0314	Undet.

[III. Crag nodules from coast of Suffolk (Herapath).]

Water with a little organic matter	4.000	3.560
Salts soluble in water (chloride of lime and sulphate of soda)	Trace	Trace
Silicic acid, colored red by a little undecomposed silicate of iron	5.792	6.309
Carbonate of lime	10.280	8.959
Sulphate of lime	Distinct trace	0.611
Phosphate of lime (tribasic)	70.920	69.099
Phosphate of magnesia	Trace only	Trace
Perphosphate of iron	6.850	8.616
Phosphate of alumina	1.550	2.026
Oxide of manganese	Trace	0.016
Fluoride of calcium	0.608	0.804
	100.000	100.000
Nitrogen	.0254	Undet.

[IV. Suffolk crag phosphate (Herapath).]

Water driven off at from 300°–350° F	2.600
Water and organic matter, expelled at a red heat	9.000
Chloride of sodium, etc	Evident trace

Carbonate of lime	39.500
Carbonate of magnesia	0.520
Sulphate of lime	Distinct trace
Phosphate of lime	15.860
Phosphate of magnesia	Trace
Perphosphate of iron	9.200
Phosphate of alumina	4.708
Peroxide of iron	None
Alumina	6.212
Fluoride of calcium	1.698
Silicic acid	10.601
	99.899

[V. Suffolk phosphate nodules, by Herapath.]

Water and organic matter	7.200	9.210
Chloride of sodium and sulphate of sodium	Trace	Trace
Carbonate of lime	18.514	5.176
Carbonate of magnesia	0.855	2.016
Sulphate of lime	Some	1.161
Phosphate of lime	51.018	45.815
Phosphate of magnesia	Trace	Trace
Perphosphate of iron	8.902	12.476
Phosphate of alumina	2.700	6.387
Oxide of maganese	0.057	0.267
Peroxide of iron	.....	.....
Alumina	.....	.....
Fluoride of calcium	3.161	2.688
Silicic acid and loss	7.593	14.804
	100.000	100.000
Nitrogen	0.0289	0.0198

PHOSPHATES OF BELGIUM.

The phosphate deposits of Belgium belong to the upper part of the Cretaceous formation. They are mined almost exclusively in the province of Hainaut, which is the southern part of the kingdom, and borders on the French province of Aisne. The following section will show the general geologic relations of the phosphate beds of this region:

Tufeau de Ciply (Ciply Marl)[1]	Craie de Maëstricht (in part).
Poudingue de Ciply (Ciply Conglomerate)	
Craie Grise ou Brune (Brown or Gray Chalk)	
Craie Blanche (White Chalk).	

The top bed, Tufeau de Ciply, is a soft, coarse-grained, calcareous rock of a white or light yellow color. It crops out in numerous places in the communes of Cuesmes, Hyon, Ciply, and Mesvin, and rests uncomformably on the underlying beds. In Cuesmes it comes in direct contact with the White Chalk (Craie Blanche), but in Ciply and Mesvin it is separated from it by a considerable thickness of intervening strata,

[1] In his recent memoir (Quart. Jour. Geol. Soc. London, pp. 325–340, 1886) Mr. Cornet expresses the opinion "that the Brown Phosphatic Chalk of Ciply and the Chalk of Spiennes should be regarded as forming together one geological whole, a peculiar stage *of the Belgian Cretaceous* series."—N. S. S.

as shown in the section above. Immediately under the Tufeau comes the Ciply Conglomerate. This is a denudation deposit, and is known as the Poudingue de Ciply, or Poudingue de la Malogne.[1] In some places it immediately overlies the White Chalk, as in the neighborhood of Ciply, and at others it is separated from it by a very variable thickness of Gray or Brown Chalk. The Conglomerate consists of a mass of phosphatic nodules, shell casts, and fossils, cemented by a calcareous matrix. Sometimes the bed is cemented into a solid mass, and again it is loose, and easily worked with pick and shovel. There are numerous shells and remains of gasteropods, lamellibranchs, brachiopods, sea-urchins, and sponges. There are, also, many teeth and vertebrate bones of fish and sharks, all much worn and rounded, showing clearly that they have been changed from the bed in which they were originally deposited. *Belemnitella mucronata* and *Ostrea vesicularis* are among the common forms found in the bed.[2] The nodules vary from a quarter of an inch to 5 inches in diameter, and are generally of a brown color. They contain a small quantity of phosphate of lime (25 to 50 per cent.) compared with that of American and English phosphates, which rarely run under 55 per cent. and 50 per cent. of phosphate, respectively. When ground and heated in a dark room the Ciply phosphate shows the same phosphorescence as the Spanish phosphorite, but in a less degree. The nodule bed is very continuous at the base of the Tufeau de Ciply,[3] but is generally in such a thin sheet that it does not pay to work it. Occasionally, however, it has been collected in pockets on the surface of the underlying bed, to such an extent that it has been mined with profit. Such is the case in Cuesmes and Ciply, where openings have been made and large quantities of phosphate taken out. The thickness of the bed is very variable, ranging generally from a few inches to 3 feet. The underlying bed is much worn and eroded on the top.[4]

It is from the bed immediately underlying the Ciply Conglomerate that over nine-tenths of the phosphate now mined in Belgium is obtained. This bed is known as the Craie Grise or Craie Brune, and comes between the Ciply nodule bed and the White Chalk (Craie Blanche). It is of a very variable thickness, being in some places entirely eroded, so that the Ciply Conglomerate comes in direct contact with the White Chalk. At other localities it reaches a very considerable thickness, as near the town of Ciply, where it is 30 meters deep. The bed consists of a coarse-grained rock, easily crumbled in the fingers, softer at the top than at the bottom, and of a gray or brown color. It is formed of a mixture of grains of carbonate of lime and small pebbles of phosphate of lime, about the size of a pin head. The proportions of the two constituents

[1] Cornet and Briart: Bull. Acad. roy. Belgique, 2d series, vol. 37, 1844, pp. 338, 844.
[2] F. L. Cornet: Bull. Soc. géologique France, 3d series, vol. 2, 1874, p. 570.
[3] Mr. Melsens: Bull. Acad. roy. Belgique, 2d series, vol. 38, 1874, pp. 25–52.
[4] F. L. Cornet: Bull. Soc. géologique France, 3d series, vol. 2, 1874, pp. 567–577.

are about 25 to 30 per cent. of grains of carbonate of lime, and 70 to 75 per cent. of phosphatic pebbles. The phosphate grains are equally plentiful all through the upper 10 feet of the bed, but below this they begin to grow scarcer and scarcer, until the bed gradually runs into the White Chalk (Craie Blanche). In this lower bed no phosphatic nodules are found, but in their place there occur beds of brown, siliceous nodules lying between the strata. The overlying phosphate bed (Craie Grise or Craie Brune) is a regularly stratified deposit and dips gently to the northwest.

The phosphate grains were at first thought to be glauconite which had been turned brown by weathering. They are of a brown color and are very porous. When exposed to the action of heat for some time they become crumbly and very easy to grind. This is explained by Mr. Nivoit[1] as being caused by the decomposition of the animal matter in the nodules. The specific gravity is 1.80 to 2.90. The phosphatic bed runs in a band of several hundred meters' breadth, through Cuesmes, Hyon, Ciply, Mesvin, Nouvelles, and Spiennes, all in the province of Hainaut. Estimating the surface of the belt as 180 hectares (444.78 acres), and supposing that mining can be carried on to a depth of 8 meters, there would be 14,500,000 cubic meters of workable rock in the place.[2]

The upper part of the phosphate bed averages 11.50 per cent. of phosphoric acid (see analyses p. 107). A large part (50 to 55 per cent.) is composed of carbonate of lime. Numerous methods have been tried to separate the phosphate from the matrix. Treating the mass with hydrochloric acid[3] has been tried, in the hope of dissolving out the carbonate and leaving the phosphate untouched, but it was found that the acid attacked the phosphate at the same time as it did the carbonate. Another method is to expose the mass of nodules and matrix to the air for some time in order to allow it to disintegrate. It is then separated from a part of the associated carbonate of lime by shaking on a screen, or washing in a stream of running water, which carries off the more finely divided part of the carbonate. Sometimes the rock is ground, and a considerable part of the limestone removed by a fan. This method is, however, not as efficient as the washing process, and is only used where water is scarce. By none of these processes has the quality risen above 40 to 50 per cent. phosphate of lime.[4]

An examination of the analyses given will show that the freer the phosphatic grains are from the calcareous matrix, the nearer they approach in composition to the nodules of the Ciply Conglomerate.[5] They

[1] Mr. Nivoit: Comptes rendus Acad. sci., Paris, vol. 79, 1874.

[2] Cornet and Briart: Bull. Acad. roy. Belgique, 2d series, vol. 37, 1874, p. 841.

[3] A. Petermann: Bull. Acad. Sci. Roy. Belgique, vol. 39, 1875, p. 31.

[4] According to Cornet experiments are now in progress which indicate that the proportion of phosphate may be raised to 65 per cent. See Quart. Jour. Geol. Soc. London, vol. 42, 1886, p. 334.—N. S. S.

[5] *Mr. Nivoit: Compt.* Rendus Acad. sci., vol. 79, Paris, 1874.

resemble very much in composition the nodules of the Marnes Crayeuses in France. The Poudingue de Ciply and the underlying Craie Grise or Craie Brune combine to make a formation very similar to the phospbate conglomerate of New Hanover County, the Poudingue resembling the upper part of the New Hanover bed and the Craie Grise or Craie Brune resembling the lower part. As will be seen by referring to the description of the North Carolina bed, the upper part contains much larger nodules and is more compact than the lower part, which is of a loose texture and has nodules of more uniform composition than the upper part. The nodules of the lower part of the New Hanover bed resemble those of the Craie Grise or Craie Brune both in decreasing in quantity at a depth and in their brown color. The principal differences are that the American beds are of Tertiary age, while the Belgium beds belong to the Cretaceous period. The nodules are smaller in the Chalk beds than in the lower part of the New Hanover beds, while the nodules of the Ciply Conglomerate are apt to be larger than those of the upper New Hanover bed. Also, the nodules of the upper part of the New Hanover beds are of more variable physical and chemical character than those of the Ciply Conglomerate.

The phosphates of the Ciply Conglomerate bed were discovered as early as 1858 by Mr. Lehardy de Beaulieu,[1] and were described again in 1866 by Messrs. Cornet and Briart.[2] But it was not until 1873 when Messrs. De Cuyper and Gendebien and Mr. Desailby opened mines, that the phosphates of Belgium were worked.

The phosphates of the Craie Grise were discovered in 1873 by Messrs. Cornet and Briart,[3] and since that time they have been almost the only beds worked, as they have proved more profitable than the Conglomerate bed. The mining is generally done in open trenches, though shallow shafts are sometimes sunk, and horizontal galleries are run in from the sides for a distance of 10 to 12 meters.

[1] Mémoires et Pub. Soc. sci. Hainaut, 2d series, vol. 7, 1860.

[2] Bull. Acad. Roy. Belgique, vol. 22, 1866.

[3] Bull. Acad. Roy. Belgique, vol. 37, 1874.

NOTE.—As this report is going to press I have received a memoir of Mr. F. L. Cornet, published in the Quarterly Journal of the Geological Society of London, August 2, 1886, pp. 325–340, entitled "On the Upper Cretaceous series and the Phosphatic beds in the neighborhood of Mons (Belgium)." This valuable memoir contains some important information concerning the geological and economic history of the region about Mons. The most important points are summarized below:

Production of the Mons district in English tons.

Year.	Tons.	Year.	Tons.
1877	3,850	1881	29,528
1878	5,630	1882	40,043
1879	7,578	1883	58,660
1880	15,500	1884	85,000

The most important points set forth in this contribution concern the circumstances which have led to the formation of the phosphates of the Mons district. The author

Analyses of the amorphous nodular phosphates of Belgium.

[I. Ciply Conglomerate nodules (A. Petermann, Bull. Acad. roy. Belgique, vol. 39).]

Water and organic matter	6.39
Carbonate lime	40.55
Phosphate lime (21.82 phosphoric acid)	47.63
Sulphate lime	3.19
Silica	0.31
Magnesia (chlorine and alkalies not determined)	1.93
	100.00

[II. Nodules (Nivoit, Assoc. franç. avanc. sci., 1875).]

Constituents.	From Perthes, at base of Craie Blanche.	From Ciply Conglomerate.	Craie Grise (whole mass, nodules and matrix).
Loss by calcination (1)	25.10	25.55	31.00
Sand and clay	1.65	1.30	2.10
Oxide of iron	1.20	0.90	1.10
Lime	50.89	51.00	54.00
Phosphoric acid (2)	21.10	20.35	11.13
Sulphuric acid	.....	0.12	.....
Chlorine	0.14	0.25	.....
Fluorine	.....	0.18	.....
	100.08	100.25	99.33
(1) Equal to phosphate of lime	46.06	44.42	24.30
(2) Nitrogen *a*	0.25	0.35	.....

a Some of the nitrogen is in the form of ammonia salts.

clearly shows that these phosphates have been formed by the concentration of phosphatic matter originally disseminated in lime carbonate, the concentration having been effected by the action of water, containing carbonic acid gas derived from decayed vegetation. Even in its somewhat concentrated form the proportion of lime phosphate is too low and that of lime carbonate too high for the material to be used in the manufacture of superphosphates. "But," says the author, "by simple mechanical processes, either by dry or wet methods, a product is obtained which contains from 40 to 50 per cent. of phosphate. Some experiments now being made lead us to hope that a proportion of 65 per cent. may be reached." These experiments in concentration have a great interest to us, for the reason that they may show the way by which the low-grade phosphates of Alabama and other parts of this country can be utilized.

The diagrams accompanying this report are of interest, as they show the relation of the phosphatic deposits to the erosive agents which have served to bring about this concentration in superficial beds.—N. S. S.

[III. Craie Brune (Nivoit, ibid.)]

Constituents.	Nodules and matrix mixed.	Washed nodules.
Organic matter	2.83	4.40
Lime	53.24	52.00
Magnesia	0.12	Trace
Alumina and oxide of iron	1.01	1.29
Potash and soda	0.19	0.28
Carbonic acid	28.10	24.32
Sulphuric acid	0.89	0.92
Phosphoric acid	11.66	15.19
Silica and sand	1.96	1.60
Chlorine and fluorine	Trace	Trace
	100.00	100.00

[IV. Craie Brune (Petermann, Bull. Acad. Sci. roy. Belgique, vol. 39, p. 34).]

	Phosphoric acid.
(*a*) Mass poor in phosphate grains	10.00
(*b*) Mass poor in phosphate grains	9.27
(*c*) Mass rich in phosphate grains	13.90
(*d*) Incoherent fragments	10.87
(*e*) Incoherent fragments	11.62
(*f*) Incoherent fragments	10.87

[V. Craie grise ou brune (Nivoit, Assoc. française avanc. sci., 1875).]

Loss by calcination	31.00
Sand and clay	2.10
Phosphoric acid	11.13
Lime	54.00
Oxide of iron	1.10
Loss and undetermined matter	0.67
	100.00

PHOSPHATES OF NORTHERN FRANCE.

The phosphates of northern France occur mostly in the provinces of Ardennes and Meuse, though they are also found in smaller quantities in other northern provinces. They are in the Cretaceous, and, like the phosphates of the English Cretaceous, appear both at the summit and base of the Gault (Gault Argileux). But there is also a third bed, which is not found in England, and which occurs immediately under the Craie Blanche, a calcareous bed corresponding to the Upper Chalk of England. The following section will show the relative positions of these beds, in descending order:

(1) Craie Blanche ("Upper Chalk").
(2) Marnes Crayeuses ("Chalk Marl").

(3) Sables Glauconieux (Chloritic Marl of England).
(4) Gaize (Upper Greensand of England).
(5) Gault Argileux (Gault of England).
(6) Sable Vert (Lower Greensand).

The above section can be seen in many places in the western part of the provinces of Ardennes and Meuse.

The nodule beds in the Upper and Lower Greensand resemble, in many respects, the corresponding beds in England. The Lower Greensand has a very variable thickness, sometimes running out almost entirely, and at others attaining a depth of 50 feet. It is at the base of this mass of sandy clay, colored sometimes by grains of glauconite, that the Lower Greensand phosphate bed occurs.[1] The nodules are rounded, worn, and mixed with many fossils and shell casts. They vary from the size of a nut to that of a man's fist. They are of a brown color, and are generally of a lighter hue on the surface than in the center. Sometimes the nodules occur loose in the sand and at others, as at Clermont and Varennes, they are cemented into a conglomerate. There are in the bed numerous shark teeth, shells, remains of crustaceans, and other fossils. The nodules often contain grains of quartz and greensand, veins or crystals of pyrite, gypsum, and sometimes of galena. There are also often associated with them concretions of pyrite, crystals of gypsum, and balls of ferruginous clay.

The French nodules resemble the English in being of a variable consistency, sometimes being very compact and glassy in appearance, and at others being so siliceous that they often, as at Beurey, look like grains of sand cemented by a little phosphate. It has already been shown that the composition of such nodules, at least so far as the relative amounts of silica and carbonate of lime are concerned, depends largely on the character of the water bottom from which the nodules were formed.

The nodule bed of the French Lower Greensand is very continuous and rarely runs out,[1] though it varies considerably in thickness, ranging from two to nine inches, and averaging about seven inches.[2] There are also nodules, more or less phosphatic, scattered through the overlying Lower Greensand, as well as through the Gault, but they are not in sufficient quantities to be of any commercial importance. The nodules and shell casts of the Gault are much more homogeneous and compact in their composition than those of the Lower Greensand.[3]

The next phosphate bed, in an ascending series, comes in the Upper

[1] Mr. Nivoit: Assoc. franç. avanc. sci., 1875.

[2] The nodules contain 8.80 to 50.54 per cent. phosphate of lime and average 39 per cent.

[3] It will be seen that there is only one regular bed of nodules in the French Lower Greensand, while in the English formation of the same horizon there are three beds, which, however, often run into each other and form one stratum.

Greensand, or "Gaize," which is a lenticular deposit lying between the Gault beneath and the Sables Glauconieux above. It reaches its maximum thickness of 105 meters near the town of d'Antry. It runs out in the north at d'Attigny and in the south near Nettancourt. It is a more or less clayey and siliceous deposit, often containing a large amount of silica in a semi-gelatinous form. The phosphate bed lies about 50 feet from the base of this deposit, and is irregular and undulating. It is of variable thickness, ranging from two to twelve inches and averaging about five inches.[1] The nodules average 55 per cent. phosphate of lime and are of the same general character all through the bed. Their surface is black or dark green, and is richer in phosphate than the interior, which is often simply a mass resembling in every respect the Gaize formation surrounding the nodules. In this respect these resemble some of the English phosphates, which are often found to contain 50 per cent. of phosphate on the exterior part, while towards the interior the quantity of phosphoric acid grows less and less till, in the center of the nodule, there is a mass of marly sand or sandy marl. The fossils are very numerous and are all much rolled and worn. In the Sables Glauconieux, which overlie this bed, there are found very similar nodules. They do not, however, occur in a regular stratum, but are scattered through the formation.

The last bed of phosphate, in an ascending series, which is found in the Ardennes and Meuse Cretaceous, lies at the base of the Craie Blanche (Upper Chalk), and on top of the Marnes Crayeuses (Chalk Marl). These nodules differ considerably from the underlying phosphates. They are of a white or gray color, homogeneous in composition, and consist almost entirely of carbonate and phosphate of lime. The bed is of very little commercial importance, as it is thin, irregular, and apt to run out.

All these French Cretaceous phosphates are very soft and porous, and can absorb a large amount of water. They easily disintegrate on exposure to air, and are readily ground to an impalpable powder. In fact, those of the Marnes Crayeuses are so soft that they go to pieces while being washed, and are, therefore, not much used. The French differ from the Belgium nodules in having more siliceous matter and less carbonate of lime.[2]

The nodules are dug in trenches or in shafts, from which galleries thirty to forty feet long are run. They are washed by throwing them on a screen over which a stream of water is running, thus reducing the mass to from one-half to one-third of its original weight. When water is scarce they are allowed to lie exposed to the air until dry, and then shaken on a screen. Thus cleaned they retain 10 to 15 per cent. of their original matrix. They are then broken and ground.

[1] Nivoit: Assoc. franç. avanc. sci., 1875.

[2] Mr. Nivoit thinks that the nodules were formed by a phosphatic solution coming in contact with carbonate of lime either already deposited or being deposited.

The principal phosphate mining districts are the canton Grand Pré, in Ardennes, and the cantons Clermont, Louppy-le-Château, and Villotte, in Meuse. The nodules of the Lower Greensand have been more extensively mined than the other beds, having been worked in seventy communes; while the Upper Greensand nodules are worked in twelve, and the Marnes Crayeuses in only one commune (at Sainte Marie, near Vauziers). The nodules at the base of the Craie Blanche have not been profitably worked in either Ardennes or Meuse.

The production of phosphate of lime from the north of France in 1875 was 66,000 tons, of which 41,000 came from Meuse and 25,000 from Ardennes, and 1,500 workmen were employed in washing and mining.

Following is a table[1] showing the cost of mining and shipping one cubic meter of nodules from the Lower Greensand, allowing 1,500 kilograms to the cubic meter. Also a table showing the expense of treating in the same way one cubic meter of Upper Greensand nodules, allowing in this case a weight of 1,600 kilograms to the cubic meter.

Cost of mining and shipping phosphates of northern France.

Items of expense.	Lower Greensand.	Upper Greensand.
	Francs.	*Francs.*
Cost for right to dig	4.00	10.00
Extraction	15.75	31.00
Transportation to washers and from them to mill	4.00	4.00
Washing	2.50	5.00
Grinding and putting in bags	9.00	10.40
Shipping (expédition)	1.75	2.50
Extra costs (traisgénéraux)	5.00	5.00
Total for a cubic meter	42.00	67.90
Total for a ton	28.00	42.45

Analyses of amorphous nodular rock phosphates of northern France.

[I. Grand Pré nodules, Upper Greensand, by Nivoit.]

Loss by calcination	8
Clay, sand, and greensand	42
Phosphoric acid	20
Lime	27
Oxide of iron	3

[II. Nodules from base of Craie Blanche by Nivoit.]

Loss by calcination	25.10
Clay and sand	1.65
Phosphoric acid	21.10
Chlorine	0.14
Lime	50.89
Oxide of iron	1.20
	100.08

[1] Nivoit: Assoc. franç. avanc. sci., 1875.

[III. Similar nodules, analyzed at the École des Mines, Paris.]

Silica	4.80
Alumina and oxide of iron	3.20
Carbonate of lime	45.82
Phosphate of lime	46.13
	100.00

[IV. Sables Verts nodules, by Nivoit (Assoc. franç. avanc. sci., 1873).]

	I. From Islettes.	II. From Louppy le Château.	III. From d'Andernay.	IV. From Beurey.
Loss by calcination	15.00	9.60	10.50	8.00
Sand and clay	27.98	23.80	31.03	39.80
Phosphoric acid	18.72	22.03	18.78	16.30
Sulphuric acid	.....	2.12	0.89	0.92
Oxide of iron	4.30	11.30	15.65	10.60
Lime	21.00	29.33	20.80	22.00
Magnesia	2.10	Trace.	Trace.	0.89
Loss and matter not determined	0.90	1.82	2.35	1.49
Total	100.00	100.00	100.00	100.00

[V. Gaize nodules from Grand Pré, by Nivoit.]

Loss by calcination	7.20
Sand and clay	13.50
Phosphoric acid	31.00
Sulphuric acid	1.00
Oxide of iron	7.50
Lime	38.50
Loss and matter not determined	1.30
Total	100.00

[VI. Nodules from the Marnes Crayeuses, Sainte-Marie, by Nivoit.]

Loss by calcination	16.20
Sand and clay	26.30
Phosphoric acid	18.00
Oxide of iron	12.15
Lime	27.35
Total	100.00

PHOSPHATES OF CENTRAL FRANCE.

The phosphates of the center of France, in the department of Côte-d'Or, and in the southeast, near the source of the Rhone, around Bellegarde, are of the Lower Gault and Lower Greensand formations. They differ in no material way from the corresponding beds in Ardennes and Meuse. The same formations are worked farther south along the Rhone, at Seyssel, near Grenoble, and elsewhere. In Isère and Drome there is a bed not represented in the north; it is a thin, glauconitic stratum, lying between the Valenginien and the Marnes d'Hauterive. It contains *Belemnites dilatatus* and *Belemnites pestilliformis*. The same

bed also crops out near Castellane and Nice. It is of very little commercial importance.

The phosphate bed of Côte-d'Or consists of a bed of yellow sand of fine texture, mixed with shells, fossils, and phosphatic nodules, which often form a separate bed in the sand. The bed immediately underlies the gray and red clays of the Gault.

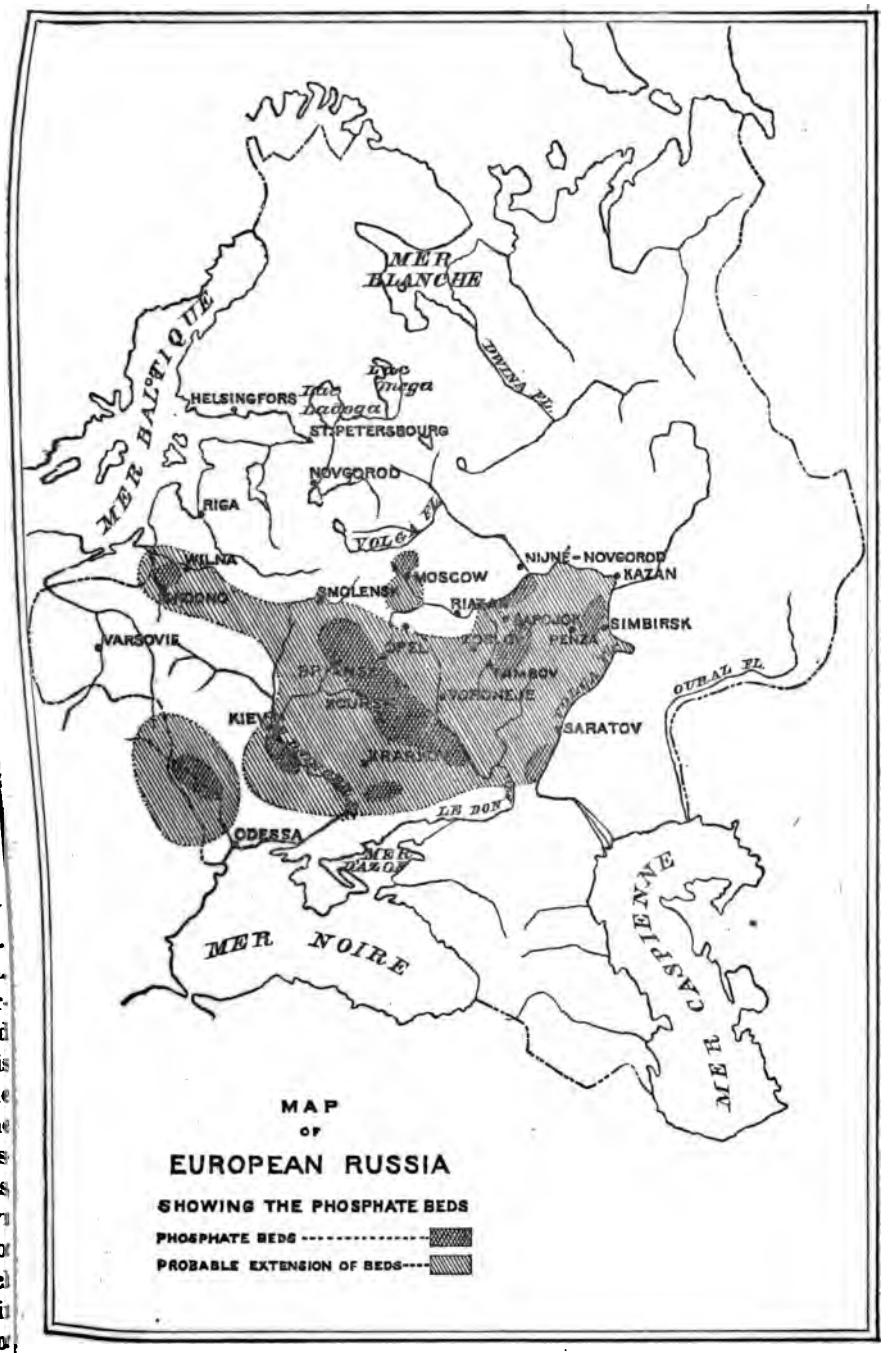
PHOSPHATES OF RUSSIA.

The principal phosphate deposits in Russia are found in the Cretaceous formation, though deposits of very limited extent have also been found in the Tertiary, Jurassic, and Silurian. The Cretaceous phosphates are developed here on a larger and more continuous scale than those of any other part of Europe or those of America. The main deposit lies between the Volga and the Dnieper Rivers, and the area covered has been estimated by Yermoloff at 20,000,000 hectares (about 50,000,000 acres). It begins in the government of Smolensk and extends almost uninterruptedly in a southeasterly direction to beyond Woronesch. This area is about 370 miles long by 60 to 125 wide. South of this belt the phosphate bed is lost under the overlying beds, but it reappears again on the southern boundary of the Cretaceous basin. North of Woronesch the bed has been destroyed by erosion, but it is found again 125 miles northwest, in the neighborhood of the villages of Tambof and Spask and Simbirsk. Besides these principal localities the phosphate bed is found in several other places between the Baltic, Caspian, and Black Seas. Mr. Yermoloff,[1] in speaking of the great extent of the Russian phosphates, says:

Nous ne croyons pas exagérer en affirmant que la Russie centrale repose sur du phosphate de chaux, qu'elle pourrait en paver la moitié de l'Europe, tant les couches qu'elle renferme sont inépuisables de richesses.

The Cretaceous series in central European Russia forms a basin, only the northern boundary of which has as yet been thoroughly explored. The phosphate beds are found at two different horizons in this formation. The first is at the base of the White Chalk or Craie Blanche, and corresponds to the White Chalk bed of Ardennes and Meuse. The second is at the base of the Greensand (Cenomanian, or Grès Verts) and is mixed with glauconite and sand. It corresponds to the beds of the same horizon in central and northern France. The deposit at the base of the Chalk is the most important, and the one most often seen. The phosphatic material occurs in the form of shell-casts, nodules, and fossils mixed together in a bed of gray or yellow sand, and is commonly known as "ssamorod" (native stone). The nodules are of a black-brown or gray color, and are often cemented together, forming a solid mass, which is used as a building and paving stone. The phosphate often occurs in several different beds, separated only by a thin layer of calcareous or

[1] Alex. Yermoloff: Jour. agric. pratique, 1872.


MER BLANCHE
MER BALTIQUE
DWINA FL.
Lac Onega
Lac Ladoga
HELSINGFORS
ST.PETERSBOURG
NOVGOROD
RIGA
VOLGA FL.
WILNA
MOSCOW
NIJNÉ-NOVGOROD
KAZAN
GRODNO
SMOLENSK
RIAZAN
SIMBIRSK
PENZA
VARSOVIE
OREL
TAMBOV
VORONEJE
OURAL FL.
KIEV
SARATOV
LE DON
ODESSA
MER D'AZOF
MER NOIRE
CASPIENNE MER
MAP
OF
EUROPEAN RUSSIA
SHOWING THE PHOSPHATE BEDS
PHOSPHATE BEDS
PROBABLE EXTENSION OF BEDS

siliceous matter. There are usually from one to three of these separate beds and sometimes as many as seven. Their thickness varies from 6 to 20 inches.

The following sections by Dr. C. U. Shepard, jr., will show the position of the phosphate beds:

Section 1. In the township of Briansk, government of Orel, on the banks of the Desna, the ssamorod occurs in large flat pieces, 3 to 4 feet square and 10 inches thick.

The order of occurrence is as follows:

(1) Argillaceous marl.

(2) White chalk.

(3) Siliceous marl, with thin layers of chalk and small nodules of phosphate of lime 1½ feet thick.

(4) Ssamorod occurring (as above described) in flat slabs.

(5) White sand 2 feet thick.

(6) Second deposit of ssamorod, in nodules; 8 inches thick.

(7) Brown sand over 5 feet thick.

The upper deposit of phosphate slabs consists of hard brown nodules, cemented together by siliceous and calcareous matter. The lower layers are dark green and soft when first dug.

Section 2. The same slabs also occur in the neighborhood of Kursk and towards Orel. At Dmitrovsk the occurrence is as follows:

(1) Red clay, 7 feet thick.

(2) White, calcareous marl, containing many small, phosphatic nodules, 4 feet thick.

(3) Very small nodules of phosphate cemented by calcareous matter, 14 inches thick.

(4) Thin layer of brown quartz sand with small nodules.

(5) Phosphatic slabs, 10 inches thick.

These slabs are not flat on the upper side, but irregular and kidney-formed. The size of the slabs varies considerably; some are as large as 3 feet long by 2 wide.

Section 3. The occurrence at Jablovsk is as follows:

(1) Soil and earth.

(2) Marl, a few feet in thickness.

(3) Chalk, a few feet in thickness.

(4) Siliceous marl, with fine grains and pebbles of phosphate, 1 to 2 feet thick.

(5) Sand a few inches thick.

(6) Phosphate rock.

Here the rock comes to sight on the sides of water-worn gullies in the rolling country.[1]

The phosphate stratum underlies an immense extent of country, but it is often at such an inaccessible depth, that most of it is of but little practical value, and it can only be profitably mined where it crops out in the ravines. Besides their inaccessibility, the nodules are of poor quality, varying, as they do, in their content of phosphoric acid from 12 to 35 per cent., and averaging only 20 per cent.[2] The nodules are very siliceous, the grains of sand being plainly visible in them. In this respect they very much resemble the North Carolina Tertiary phosphates.

[1] Dr. C. U. Shepard, jr., MSS.

[2] Alex. Yermoloff, Jour. agric. pratique vol. 1, 1872.

When the nodules are cemented together in slabs, the masses are generally 1 to 2 feet square and 8 to 12 inches thick. Their upper surface is smooth, shiny, and mammillated; the lower one, which is irregular and uneven, shows plainly that the slabs are composed of nodules held together by a siliceous and calcareous cement.

According to Yermoloff the beds of Smolensk, Orel, Kursk, and Woronesch contain not less than 6,000 tons per acre, while those of Tambov, which are said to be the richest in Russia, contain 20,000 to 30,000 tons per acre.

As regards the origin of these phosphates, Count Keyserling thinks that they were formed by carbonated waters dissolving the phosphate of lime of the bones and other phosphatic matter of dead animals and redepositing it in a bed of siliceous and calcareous marl.

The existence of ssamorod in central Russia has been known ever since the early part of this century, but its value was not appreciated. In the geological survey of Russia, by Sir R. Murchison, the phosphate rock is simply spoken of as "a shelly agglomerate and concretionary iron-stone," and several deposits of it are spoken of as "ferruginous, siliceous, and concretionary banks." The discovery that ssamorod is a phosphatic rock is due to Professor Chodneff, of St. Petersburg, in 1845. Count A. Keyserling and Professor Claus, of Dorpat, first made known the existence of phosphate in the departments of Kursk and Woronesch a few years later. In 1866, Professor Engelhardt, in his geological survey of Russia, afforded valuable information concerning the extent, value, and accessibility of the phosphatic beds.

Several factories have been started to make use of these deposits, but generally with little success. Large works were started at Ukolowa, Riga, and in Kursk, but were soon closed. The phosphate is of too low grade to pay for the expense of mining it.

Besides the beds already described, phosphatic deposits of much more limited extent have been found elsewhere in Russia. Thus Professor Schwackhofer,[1] of Vienna, has discovered a deposit of phosphatic nodules in the Silurian schists of Poland, on the Dniester. The average of twenty-five analyses gave 74.23 per cent. bone phosphate, which is much higher than the average of Russian Cretaceous phosphates. The amount of phosphatic material in the bed is, however, very limited, and consequently it is of no commercial importance. A phosphatic limestone containing 12 per cent. of phosphoric acid had also been discovered in the government of Novgorod.[2]

[1] Ueber das Vorkommen und die Bildung von Phosphoriten an den Ufern des Dniesters in Russisch-Podolien, Galizien und der Bukowina, by Professor Schwackhofer.

[2] A. Yermoloff, Jour. agric. pratique, vol. 1, 1872.

Analyses of the amorphous nodular phosphates of Russia.

Analyses given Dr. C. U. Shepard, jr., by T. Lahusen, of the Imperial School of Mines, St. Petersburg.]

[With the exception mentioned under the head of notes all the samples analyzed were nodular.]

Locality.	Government.	Chemist.	Bone phosphate of lime.	Sand.	Notes.
Belskaga in Roslavl.	Smolensk.	Engelhardt...	31.15	43.69 to 50.13	Siliceous.
Do	....do	Kostytscheff..	60.42 to 63.39	5.51 to 7.61	Argillaceous.
Beschti in Roslavl.	....do	Schmidt	36.18	44.57	Siliceous.
Brianck	Orel	Engelhardt...	35.25 39.26	39.77 37.43	Green and soft. Brown and hard.
Do	....do	Latschinoff...	33.37	48.25	Prepared phosphate meal.
Voronova	....do	Malyschaff...	45.36	28.79	
Linbachina in Brianck.	....do	Morkjraff	31.92	47.47	Gray.
Do	....do	Latschinoff...	62.65	9.15	Black.
Kotovetz in Schtyrovosk.	Kursk	Malyschaff...	59.01	11.97	Cemented in siliceous chalk.
Kursk	....do	Latschinoff...	28.92 to 30.89	57.10 to 53.70	Upper side of flat cakes. Lower side.
Curoff	Woronesch	Malyschaff...	36.87	44.92	
Pendovischti...	....do	....do	29.92 to 40.47	43.29 to 50.45	
Bondary	Tambov ..	Yermoloff	36.18 to 41.24	45.26 to 35.50	
Bytschkoff	....do	....do	15.98 to 60.76	13.03 to 54.16	
Spask	....do	....do	60.00	9.50	
Do	....do	....do	40.32	41.28	
Do	....do	....do	58.64	12.25	Argillaceous.
Do	....do	....do	27.57	59.70	Do.

Analysis by Dr. C. U. Shepard, jr., of phosphate rock ground at the mill at Ukolowa, Central Russia.[1]

Quartz	34.05
Organic matter	0.90
Sulphate of lime	1.60
Bone phosphate of lime	42.05
Carbonate of lime	12.23
Fluoride of lime	6.98
Phosphate of magnesia	1.30
Alumina and oxide of iron	1.16
	100.27

[By Dr. C. U. Shepard, jr., Jablovsky phosphate rock.[2]]

Phosphoric acid	13.35
Equivalent bone phosphate of lime	29.14
Sand and insoluble siliceous matter	54.40

[1] Ground phosphate rock partially freed from sand.

[2] A superphosphate made from 12 parts (by weight) of this phosphate and 9 parts of sulphuric acid (specific gravity 1.50) gave a product which was wet, sticky, and acid.

[Analysis of Russian phosphate rock, by Yermoloff.]

Phosphoric acid	20.26
Lime	29.07
Magnesia	0.00

[Russian rock phosphates, by Yermoloff.]

	Clay and sand.	Phosphoric acid.	Carbonic acid.	Sulphuric acid.	Lime.	Magnesia.	Alumina and oxide of iron.
Block phosphate from near Kursk, by Claus	50.00	13.60	3.45	.86	21.00	0.65	2.20
Nodules from near Spask, by Yermoloff	9.50	27.48	3.95	1.06	42.00	0.40	3.19
Nodules from near Spask, by Yermoloff	59.70	12.63	1.98	0.44	18.54	.....	.....
Block of nodules from one of the richest beds of the government of Tambov, by Yermoloff	35.50	20.26	.....	0.85	29.07	.....	3.47
Fossil bone from same locality as last, analyzed at Agricultural Institute of St. Petersburg	1.45	31.76	.....	.....	48.53	1.48	0.32
Fossil wood from phosphate bed near Spask, by Engelhardt	.....	35.23	3.44	.....	51.90	.....	1.15
Phosphate from government of Orel, analyzed at the Agricultural Institute of St. Petersburg	7.10	29.84	6.06	1.39	47.99	0.47	0.89

[Analysis of Silurian phosphate rock from the Dniester, by Professor Schwackhofer.]

Phosphate of lime	74.23
Sand and insoluble matter	5.61
Fluoride of lime	6.00
Oxide of iron	0.50–5.0

PHOSPHATIC LIMESTONE BEDS.

Under this heading are included those sedimentary limestones which contain considerable quantities of phosphate of lime. Such deposits have been found in Kentucky; and Yermoloff mentions that a limestone containing 12 per cent. phosphate of lime exists in the government of Novgorod, Russia.

Most limestones contain a small per cent. of phosphate, but as yet very few have been found which contain large amounts, and none are known which have become of commercial importance.

PHOSPHATIC LIMESTONES OF KENTUCKY.

Several beds of phosphatic limestone have been discovered by Prof. N. S. Shaler in Kentucky, but the one richest in phosphate of lime was found in Fayette County.[1] It belongs to the lower part of the Cincinnati group and consists of a thin stratum, never reaching a greater thickness than from 6 to 12 inches. It is a "somewhat friable rock of a bluish gray color; brownish gray on the weathered surfaces; containing many microscopic marine univalve shells. Adheres strongly to the tongue." It is much more brittle than the associated limestones, and contains 31.815 per cent. of phosphoric acid. It is probable that beds of

[1] *Geol. Survey Kentucky*, N. S. Shaler, Director, 1878, New Series, vol. 4, p. 65.

this kind derived their phosphate of lime from the numerous animals, having phosphatic shells, which inhabited the Silurian sea.

Phosphatic limestone beds, like those just described, supply the soil of the surrounding country with large quantities of phosphate of lime, and it is very likely that the wonderful fertility of some districts in the limestone regions of Kentucky and Virginia is due to the decomposition of such beds.

Analysis of Fayette County phosphatic limestone, by Dr. Peter (Kentucky Geol. Surv., 1878). Dried at 212° F.

Phosphoric acid, lime, magnesia, alumina, iron oxide	85.270
Carbonate of lime	9.180
Carbonate of magnesia	.371
Silica and insoluble silicates	4.780
Fluoride of calcium, alkalies, organic matter, etc., not estimated	.399
Total	100.000

GUANOS.

The class of guanos includes all those deposits which are largely, or entirely, composed of the excrement of birds. Such deposits are subdivided into *soluble guano* and *leached guano*. The former is composed of deposits which have preserved all, or a large part of, their soluble ingredients, while the latter includes such as have lost these soluble constituents by the action of rain or sea-water, and have been converted into a mass, insoluble, or almost insoluble, in water, and varying, in consistency, from a loose powder to a hard compact rock.

The soluble guanos will be treated first, and then the leached guanos will be described.

SOLUBLE GUANO.

Most of the soluble guano of commerce has come from the coast of Peru. It has been used in that country for agricultural purposes from very ancient times. Of such value was it esteemed by the natives that the punishment of death was imposed by the early Incas and their Spanish successors on any one who was found killing the birds that made these precious deposits. Peruvian guano was first recommended (1804) to be used in the raw state for agricultural purposes in Europe by Humboldt, who brought a specimen from the islands off the coast of Peru; but it was not exported in any considerable quantities until 1842, when 182 tons were shipped to England. After that time the use of it increased very rapidly until 1870–1875, when the best beds were exhausted, and the use of acidulated phosphates gradually drove the poorer qualities almost entirely out of the market. It is still imported to the United States and Europe as a source of superphosphate. In the raw state very little of it is used compared with the immense quantities of superphosphates now sold.

The following tables will show the imports into Great Britain, Germany, and France:

Imports into Great Britain (Stockhardt).

	Cwt.		Cwt.
1844	208,502	1855	6,101,220
1845	568,600	1856	3,830,020
1846	1,784,060	1857	5,767,240
1847	1,647,840	1858	7,070,820
1848	1,428,280	1859	1,682,440
1849	1,668,760	1860	2,828,700
1850	2,338,500	1861	3,568,460
1851	4,860,280	1862	2,832,720
1852	2,597,780	1863	4,671,480
1853	2,463,320	1872	117,089
1854	4 470,222	1873	184,921

Imports into Germany (Meyn).[1]

	Tons.		Tons.
1861	25,000	1866	55,621
1862	30,000	1867	52.413
1863	48,785	1868	73,922
1864	50,699	1869	85,233
1865	59,940		

Imports into France (Meyn).[1]

	Tons.		Tons.
1857	52,000	1862	46,000
1858	38,000	1863	68,000
1859	33,000	1864	69,000
1860	40,000	1865	47,000
1861	38,000	1866	57,000

The deposits of guano are found mostly on the islands on the coast of Peru and Bolivia. They are also found on the mainland, but these are not so large as those on the islands. The deposits consist of the excrements of flamingoes, divers, penguins, and other sea fowls, mixed with the carcasses of these birds, as well as those of seals, sea-lions, and other marine animals, which inhabit these seas in vast numbers. The guano is generally pulverulent on the surface, but becomes compact at a depth. It is in some places over a hundred feet in thickness, and is white to brown in color. There often occur in it small lumps containing ammonia salts, and others containing large quantities of phosphate of lime or silica. Gypsum is also abundant in some of the guano beds. The phosphates in the guano occur largely as tricalcic, dicalcic, ammonio-magnesic, and ammonic phosphates, so that a large part of it is in a very soluble form, hence its value as plant food. There is also in the guano a soluble base called guanine, with the formula $C_5H_5N_5O$. It will thus be seen that, though some of the ingredients of guano are insoluble, others are very soluble, and, for the preservation of such a deposit a very dry climate is necessary. The coast of Peru is peculiarly adapted to the formation of guano beds, not only on account of the absence of rain, but

[1]Die natürlichen Phosphate.

also on account of the large flocks of sea birds which inhabit the islands along the coast and feed on the vast schools of fish swarming in the surrounding seas.

The first beds that were mined were on the Chincha Islands, off the coast of Peru. The guano of this locality was the richest of all the deposits on the South American coast. The islands are small, rarely more than three miles in circumference, and the beds were practically exhausted as early as 1872. Among the other islands which have been worked and stripped of their valuable deposits are those of Macabi and Guañape, north of the Chincha Islands, as well as those of Ballestas, Lobos, Foca, Pabellon de Pica, Tortuga, Huanillos, and many other islands on the same coast. As will be seen from the analyses, the composition of the guano from these localities varies considerably. It depends on the circumstances under which the deposit was formed, such as the amount of rain, the exposure to the spray of the sea-water, and other conditions.

Though the Peruvian coast is the most important locality for guano, yet it has been obtained in considerable quantities in other places also. It is found near the Cape of Good Hope and northwest of it, at Saldanha Bay. It is also found on the island of Ichaboe, as well as at Algoa Bay, which is on the southern coast of Africa. The guano from these African localities has often been leached by the action of rain and sea water, but it is also found containing large quantities of soluble salts of ammonia and phosphorus. The island of Ichaboe contained 200,000 tons of guano, all of which was removed in fifteen months after its discovery in 1844.

Soluble guano has been found on the Kuria Muria Islands, on the coast of Arabia; at Shark's Bay, Australia, and at many other places in small quantities. The variety known as "bat guano" is generally found in caves, and consists of the dung of bats, mixed with the bodies of their dead, as well as with the remains of rats, mice, etc. Such deposits are of very limited extent. They are found in many places in America and Europe. In the United States bat guano is found in Indiana, Kentucky, Alabama, and many other States. Near San Antonio, Tex., there are several caves containing large quantities of it. It is also found in many places along the coast of the Mediterranean, and especially in Italy.

Analyses of soluble guano.

[I. Mean of 21 analyses of Macabi Island guano, by Barral.]

Nitrogen	10.90
Phosphates	27.60
Potash	2 to 3

[II. Analysis of Macabi guano, by Bobierre.]

Water	30.80
Bone phosphate	35.50
Nitrogen	8.22

[III. Analysis of Guañape Island guano, by Dr. C. U. Shepard, jr.]

Nitrogen	8.20 to 12.80
Phosphoric acid	10.77 to 17.62
Sand and siliceous matter	0.75 to 3.75
Water	11.83 to 29.96

[IV. Average of 22 analyses of Guañape guano, by Barral.]

Nitrogen	10.95
Phosphates	28.00
Potash	2 to 3

[V. Analysis of Guañape guano, by Bobierre.]

Water	24.00
Sand	1.30
Organic matter and ammoniacal salts (1)	37.00
Bone phosphate of lime	36.00
Undetermined matter	1.70
	100.00
(1) Nitrogen	7.75

[VI. Analyses of soluble guanos, by Dehérain.]

	Angamos, coast of Bolivia. White guano.	Bolivian.	Los Patos.	Island of Elide, coast of California.	Îlot de Pedro-Bey, coast of Cuba.
Organic matter	70.21 to 52.92	23.00	32.45	27.37 to 34.50	6.16
Containing nitrogen	20.09 to 14.38	3.38	5.92	1.34 to 6.98	0.28
Equivalent in ammonia	24 36 to 17.44	4.10	7.18	1.62 to 8.46	0.34
Total phosphates	13.30 to 20.95	48.60	34.81	[1] 28.00 to 31.00	48.52

	Mexican coast.	Galapagos, Ecuador.	Falkland Islands.
Organic matter	13.05 to 18.00	.....	17.35 to 28.68
Containing nitrogen	0.21 to 3.45	0.7	0.56 to 2.26
Equivalent in ammonia	0.26 to 4.19	0.85	0.68 to 2.74
Total phosphates	8.00 to 25.00	60.30	[1] 21.46 to 25.62

[1] Containing sometimes very considerable quantities of phosphates of alumina and the oxide of iron.

[VII. Analysis of Peruvian guano by Dr. Ure, Am. Jour. Agric., 1845.]

Uric acid	10.50
Ammonia	19.00
Phosphoric acid	14.00
Lime and magnesia	16.00
Salts of soda and potash	6.00
Oxalic acid, with carbonic and muriatic acids	13.00
Water	13.00
Sand	2.00
Volatile and organic matters	6.50
	100.00

[VIII. Analysis of Peruvian guano, by Nesbit, Agricultural Chemistry, London, 1859.]

Moisture	15.10
Organic matter, etc. (1)	51.27
Silica	2.20
Phosphate of lime	22.13
Phosphoric acid	3.23
Equal to phosphate of lime, 7.00.	
Alkaline salts, etc	6.07
	100.00
(1) Nitrogen	13.54
(1) Ammonia	16.42

[IX. Analysis of Ichaboe guano, Am. Jour. Agric., 1845.]

Ammonia	13.50
Humic acid	4.00
Phosphates	25.00
Oxalic, etc., acids	20.00
Salts of soda, etc	7.00
Water and volatile matter	27.50
Sand	3.00
	100.00

[X. Analyses of soluble guanos, by Nesbit, Agricultural Chemistry.]

	Angamos.		Peruvian.	Chilian.	Bolivian.	Saldanha Bay.	Shark's Bay.
	I.	II.					
Moisture	10.90	12.55	9.30	20.46	16.00	17.92	14.47
Organic matter, etc. (1)	67.36	61.07	57.30	18.50	18.16	14.08	7.85
Sand	1.04	5.36	0.75	22.70	3.16	2.80	14.47
Phosphates	16.10	13.76	23.05	31.00	60.23	59.40	29.54
Alkaline salts, etc	4.60	7.26	9.60	7.54	7.45	5.80	33.67
	100.00	100.00	100.00	100.20	100.00	100.00	100.00
(1) Nitrogen	19.95	18.24	15.54	4.50	2.11	0.63	0.35
(1) Equal to ammonia	24.19	22.12	18.87	5.47	2.56	0.76	0.47

[XI. Analyses of Peruvian guano and of Ichaboe guano; from The Cultivator, vol. 1, 1844.]

	Peruvian guano.	Ichaboe guano.
Water and volatile ammonia	15.27	8.14
Organic matter and ammoniacal salts	51.44	63.52
Chloride and sulphate of soda	5.50	5.02
Insoluble siliceous matter	0.57	1.16
Phosphate of lime and little phosphate of magnesia	21.11	22.20
Carbonates of lime and magnesia	6.11	4.96
	100.00	100.00

[XII. Analyses of soluble guano, by Norton, Elements of Scientific Agriculture, 1860.]

	Bolivian.	Peruvian.	Chilian.	Ichaboe.
Water	5 to 7	7 to 10	10 to 13	18 to 26
Organic matter and ammoniacal salts	56 to 64	56 to 66	50 to 56	36 to 44
Phosphates	25 to 29	16 to 23	22 to 30	21 to 29

[XIII. Analyses of soluble guanos, Cameron, Chemistry of Agriculture.]

	Upper Peruvian.	Ichaboe.	Bird Island.	Cuban.	Kuria Muria.	Patagonian.
Water	10.00	20.00	15.00	26.00	18.10	25.00
Organic matter	21.68	24.40	6.50	4.10	12.41	18.36
Yielding ammonia	(4.50)	(6.00)	.....	.....	(2.05)	(2.00)
Earthy phosphates	51.50	20.40	37.25	43.70	42.67	44.00
Carbonate of lime	.....	.....	40.00	24.10	4.19	.....
Alkaline salts	14.12	6.20	1.15	.....	4.13	2.10
Sand, clay, and other useless mattor	2.70	29.00	0.10	2.10	18.50	10.60
	100.00	100.00	100.00	100.00	100.00	100.00

[XIV. Analysis of soluble guano from "an island in the Pacific," by R. S. Burn, Year-Book of Agricultural Facts.]

Water	4.60	4.60
Organic matter and ammoniacal salts	16.85	16.38
Phosphates	71.40	69.50
Carbonate of lime	3.15	7.90
Alkaline salts	3.90	1.07
Sand	0.10	0.15
	100.00	100.00
Ammonia	1.32	1.26

[XV. Analysis of bat guano, Report Indiana Geological Survey, 1879, p. 163.]

Loss at red heat	44.10
Organic matter	4.90
Ammonia	4.25
Silica	6.13
Alumina	14.30
Ferric oxide	1.20
Lime	7.95
Magnesia	1.11
Sulphuric acid	5.21
Carbonic acid	3.77
Phosphoric acid	1.21
Chlorides of alkalies and loss	5.87
	100.00

LEACHED GUANOS.

The second subdivision of guano deposits is leached guano. It is either pulverulent, or in a more or less solidified mass, and consists of *guano from* which all or almost all the soluble constituents have been

dissolved by the action of rain and sea water. It is found most plentifully on some of the small islands in the Pacific Ocean, northeast of Australia, and on many of the West India Islands. It is also found in some places on the coast of Chili, as on the promontory of Mexillones. Here it occurs as a light yellow phosphatic powder, containing lumps of the same substance and averaging 75 to 81 per cent. of bone phosphate of lime.

Leached guano is found in the Pacific principally on the islands lying between longitude 150° to 180° west and latitude 10° N. to 10° S. Most of this area was put by Congress under the protection of the United States in 1856. It contains some forty guano islands. They are all small and low, and are built up by the formation of coral reefs. Often there is a salt-water lagoon in the center of the island. Among the richest localities are Baker, Howland, Jarvis, McKean, Malden, Starbuck, and Phœnix Islands. The guano is generally pulverulent on the top, and more or less solidified below. Occasionally the soluble portions have been washed into the underlying coral, forming a phosphatic limestone. The following is a section on Baker Island:

(1) Pulverulent leached guano, yellow.
(2) Denser stratum of same substance as (1).
(3) Coral rock containing gypsum.

On Jarvis Island a bed of gypsum has been formed by the evaporation of a central lagoon. Overlying this is a deposit of leached guano, from one inch to one foot thick, covered by a phosphatic crust. Under this crust the bed contains both basic and neutral phosphate of lime. This fact is thought by Dr. C. U. Shepard, jr., to be due to the decomposition of the tribasic phosphate by the gypsum. Occasionally concretionary nodules, composed of interstratified layers of phosphate of lime and gypsum, are found. On Malden Island there is a boggy deposit, which gives off sulphureted hydrogen from the mutual decomposition of the guano and the gypsum.

In the West Indies, leached guano has been found on many of the coral islands and reefs, all the way from the Bahamas to the coast of Venezuela. Among the principal localities are Sombrero, Navassa, Turk, St. Martin, Aruba, Curaçoa, Orchillas, Arenas, Roncador, Swan, and Cat, or Guanahani Islands, the Pedro and Morant Keys, and the reefs of Los Monges and Aves in Maracaibo Gulf. The phosphate from the different localities varies very much. That from Maracaibo Gulf occurs in a compact or granular form of a light brown color. Sometimes it is distinctly mammillated, and at other times it has a concentric structure. It often has a white phosphatic enamel like that which covers the basalt of Ascension Island. The deposit contains many fish bones, and is rich in phosphate of lime, which sometimes amounts to over 85 per cent. of the rock. The Sombrero Island phosphate occurs in two forms: (1) As a granular, porous, and friable mass, in color white, pink, green, blue, or yellow; (2) as a dense, massive, and homo-

geneous deposit of a white or yellow color. It contains 75 to 80 per cent. of phosphate of lime. Many bones occur, and at times the deposit takes the form of a real bone breccia. The principal rock of the island is a palagonite tufa, filled with shells and bones.

The Navassa phosphate is found on an uninhabited island, consisting of a terrace encircled by a high plateau. The phosphate is found in pockets in the living coral, and in the numerous depressions and hollows on the island. It is of a dark brown color, and is composed of a hard mass of oölitic grains. It contains 10 to 15 per cent. of alumina and oxide of iron (Meyn), and is therefore not very popular as a source of superphosphate, as it makes a sticky product.

The phosphate of Aruba Island is of a hard, massive variety, and is white to dark brown in color. Occasionally the underlying coral on this island, as well as on many others in both the West Indies and the Pacific Ocean, has been phosphatized by the infiltration of the soluble parts of the original guano deposits. Thus at Aruba large masses of coral, containing 70 to 75 per cent. phosphate of lime, are found.

Several distinct phosphate minerals occur in pockets in the phosphate beds in the West Indies. One of them, known as pyrophosphorite, was described by Dr. C. U. Shepard, jr., in the American Journal of Science, January, 1878. It is snow white, amorphous, opaque, and has a fracture like magnesite. It has a hardness of 3 to 3.5, and a specific gravity of 2.50 to 2.53. It is essentially an ortho-pyrophosphate of lime with pyrophosphate of magnesia, and has the formula $Mg_2P_2O_7+4(Ca_3P_2O_8, Ca_2P_2O_7)$.

On the islands of Mona and Moneta, in the West Indies, occur the minerals monite and monetite. They were described and named by Prof. C. U. Shepard, sr., in the American Journal of Science, May, 1882. The monetite occurs as a crystalline mineral, of a white or brown color, in association with monite, which is a white, soft, incoherent mass. Monetite is a crystallized dicalcic ortho-phosphate and has the formula $CaHPO_4$. Monite has the formula $Ca_3P_2O_8+H_2O$.

Deposits of leached guano have been found on several islands in the Gulf of California. The deposit on Raza Island averaged over 41 per cent. of phosphoric acid, which corresponds to over 85 per cent. of phosphate of lime. (See analyses.) The beds in this island have been exhausted.

The deposits of the West Indies supply most of the leached guano now sold. Curaçoa annually produces 50,000 to 70,000 tons, and Sombrero about 10,000. The other islands produce much less. The Pacific Ocean islands are, at present, little worked. The difficulty with many of the West India deposits is that they contain large quantities of phosphate of iron and alumina, which make them very undesirable as sources of superphosphate. On some of the islands there occur beds of almost pure phosphate of iron and alumina.

Table of analyses of leached guanos.

[I. Analyses of Baker Island guano (constituents, lumps, crust, coral rock, etc.), by Siegert.]

	(1)	(2)	(3)	(4)	(5)
Water	1.45	10.25	9.03	0.90	8.20
Combustible matter (1)	2.57	5.11	4.02	4.47	8.30
Potash	0.10	0.44	0.43	0.46	0.62
Soda	0.45	0.73	0.62	1.21	1.13
Lime	53.78	43.83	43.44	45.82	40.63
Magnesia	0.27	0.42	0.60	1.89	1.75
Phosphoric acid	0.00	33.97	33.62	38.98	37.16
Sulphuric acid	1.40	2.07	6.81	1.16	1.17
Carbonic acid	39.98	3.18	1.43	5.11	1.04
Total	100.00	100.00	100.00	100.00	100.00
(1) Nitrogen	0.00	0.00	0.00	0.00	0.92

(1) Unchanged coral white rock.
(2) Yellow-brown crust, often several inches thick, with white interior, of coralline structure.
(3) Gray-brown balls, soft to pulverulent, often several inches thick; coralline structure feebly marked.
(4) Porcelain-like cakes, smooth or rough, soft, 1 to 4 inches thick, and in parallel plates.
(5) Whole guano powdered.

[II. Analysis of Howland Island guano, by Drysdale.]

Water	7.20
Combustible matter	14.18
Phosphates	75.32
Sulphate of lime	1.60
Carbonate of lime	1.27
Chloride of alkalies	0.43
Sand	Trace
	100.00

[III. Analyses of Jarvis Island guano, dried at 105 C.]

	Powder.	Lumps.
Water of combination and combustible matter	20.80	18.50
Anhydrous sulphate of lime	30.00	5.00
Phosphates of lime and magnesia	43.20	73.00
Siliceous residue	2.00	1.00
Undetermined ingredients and loss	4.00	2.50
	100.00	100.00

[IV. Analyses of Phœnix Island guano, by Rumpler.]

Water	1.19	2.08
Combustible matter	2.03	5.22
Phosphate of lime	76.00	70.70
Phosphate of magnesia	5.19	13.47
Carbonate of lime	0.68	10.50
Sulphate of lime	0.34	5.10
Nitrogen in the combustible matter	0.39	0.77

[V. Analysis of Aves guano, by Völcker.]

Water	2.39
Organic matter and water of combination	7.93
Lime	39.48
Magnesia	1.17
Phosphoric acid	41.34
Sulphuric acid	4.57
Insoluble siliceous matter	2.28
	99.16
Containing nitrogen	0.139

[VI. Analyses of Navassa phosphate.]

	Gilbert.	Bretschneider.
Water	3.01	3.54
Organic matter and water of combination	7.17	4.64
Lime	40.19	38.35
Magnesia		1.72
Sesquioxide of iron	11.67	3.40
Alumina		6.50
Potash		0.34
Soda		0.32
Phosphoric acid	33.28	35.60
Sulphuric acid		0.19
Chlorine		0.08
Carbonic acid	2.15	2.58
Silica		1.34
Sand	2.53	1.31
	100.00	99.91

[VII. Analysis of Raza Island phosphate, by Dr. H. Gilbert.]

Water	1.92
Neutral phosphate of lime	58.78
Bone phosphate of lime	18.86
Tribasic phosphate of magnesia	3.32
Sulphate of lime	8.26
Oxide of iron	0.99
Silicic acid	3.38
Organic matter	4.81
	100.32

BONE BEDS.

These deposits include beds which are composed largely of bones.[1] They occur principally as *cave* and *lacustrine* deposits.

CAVE DEPOSITS.

Caverns have always been the places of refuge and the sepulchers of many kinds of animals, and sometimes bones have collected in them in sufficient quantities to form beds many feet thick. Such deposits are

[1] The phosphate beds of South Carolina and other similar deposits do not belong under this heading, for, though many bones occur in them, they are few compared *with the accompanying* phosphatic nodules.

much larger and more plentiful in Europe than in North America. The reason for this seems to be that in this country there were none of the carnivora, such as the jackals and hyenas, which have the habit of dragging their prey to their lairs. Consequently our caverns, notwithstanding their abundance and the great number of animals which have lived about them, are generally wanting in the extensive osseous breccias which characterize many caves in England, France, Germany, Hungary, Italy, and many other parts of Europe.

Many of the caves of the Southern States have been much resorted to by bats. The excrements of these creatures, together with the bones of those that have died there, have in many cases formed extensive beds of phosphatic and nitrogenous matter.[1] During the early part of this century, and during the civil war, saltpeter was extensively manufactured from them, and some of them have also been worked as a source of phosphate of lime.

LACUSTRINE DEPOSITS.

These deposits occur generally about the swampy margins of salt licks, as at Big Bone Lick in Kentucky[2], and in the ancient lake deposits west of the Mississippi River, as in the Mauvaises Terres of Nebraska. Similar beds are also found in many parts of Europe. The bones found in such localities are the remains of animals which came to the swamps to lick the salt found there, or in search of refuge. Many died natural deaths, while others were mired in the boggy earth, and, being unable to extricate themselves, perished. In this way bones accumulated often in very considerable quantities.

These deposits, as well as those of the cave class, are generally too limited in extent to be of any commercial importance.

[1] These deposits have been described under the heading of Guanos.

[2] An account of this deposit may be found in an appendix to Mr. J. A. Allen's monograph on The History of the Buffalo, in the memoirs of the Kentucky Geological Survey, Vol. I, 1876.

A.

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J. W. POWELL, DIRECTOR

ANALYSES OF WATERS

OF THE

YELLOWSTONE NATIONAL PARK

WITH AN ACCOUNT OF THE METHODS OF ANALYSIS EMPLOYED

BY

FRANK AUSTIN GOOCH

AND

JAMES EDWARD WHITFIELD

WASHINGTON

GOVERNMENT PRINTING OFFICE

1885

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY, DIVISION OF CHEMISTRY,
Washington, D. C., April 26, 1887.

SIR: I have the honor to transmit for publication as a bulletin of the Survey a paper entitled "Analyses of waters of the Yellowstone National Park, with an account of the methods of analysis employed," by Frank Austin Gooch and James Edward Whitfield. It represents work done in the Chemical Laboratory of the Survey and it is an exceedingly valuable contribution to science.

Very respectfully,

F. W. CLARKE,
Chief Chemist.

Maj. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

ANALYSES OF WATERS OF THE YELLOWSTONE NATIONAL PARK.

By F. A. Gooch and J. E. Whitfield.

INTRODUCTION.

The series of waters—forty-three in all—of which it is the purpose of this paper to give some account comprises typical representatives of the geysers, hot springs, mud springs, cold springs, and surface waters found within the limits of the Yellowstone Park. It embraces collections made during the field seasons from 1883 to 1886 under the direction of Mr. Arnold Hague, geologist in charge of the Yellowstone Park Division, and submitted to us for analysis. In our account we have to deal simply with the results of analysis and with the analytical processes we have used—with the latter on the ground that some knowledge of the methods employed in the examination and of the quantities of material at our disposal is essential to a correct understanding of the meaning and value of the analyses themselves. Discussions of the broader chemical aspects of the problems which are involved in a thorough consideration of the relations of these waters, of correlative matters of geological interest, and of the physical phenomena belong properly to others.

The difficulties in the way of collecting and transporting large quantities of water in a region comparatively inaccessible were such that the number of large samples, for the more complete analyses, was restricted to a half-dozen; but, though at the beginning of the examination it was supposed that a partial analysis, such as might be made with smaller amounts of material, must suffice, it happened, fortunately, that the development of certain methods as the work progressed has so far extended the reach of the analyses of the smaller samples that from them it is possible to deduce results of fair accuracy, and, if such elements be left out of consideration as are shown by the more elaborate analysis to be present either not at all or only as traces in closely comparable waters, nearly as comprehensive results as those drawn from the examination of the larger samples.

OPERATIONS IN THE FIELD.

The examination of the waters was necessarily confined in the field to a very few points. Note was made of the *clearness* or *turbidity*, the *reaction* to litmus and turmeric, the *temperature*, and the presence or absence of *hydrogen sulphide*. The tests for the last were the sense of smell and the action of the water upon a polished silver blade.

The operations of collecting and preparing the samples for transportation were carried out as simply as possible. The water was bottled in boxed demijohns when it was possible, and otherwise in beer bottles. In every case great care was taken to clean the receptacle thoroughly and rinse before bottling with some of the water to be examined. In the greater number of cases the waters were so marvelously clear that filtration was entirely superfluous. When, however, the need and opportunity occurred the waters were filtered previous to bottling. All samples were corked tightly and sealed hermetically.

The size of the sample varied from a half liter to one hundred liters, according to the purpose for which it was taken; but the great bulk of the largest samples was, in every case excepting one, reduced greatly by the evaporation of the main portion of the sample previous to bottling. In the one exceptional case the sample was taken for the specific purpose of examining it as to its contents in the heavy metals, and was kept for subsequent reduction in porcelain in the laboratory, in order that the danger of contamination by the tin or copper of the tin-lined still which was employed to effect the reduction in the field might be precluded. No attempt was made to fix with more than a rough approximation the quantities of water evaporated. The concentrated waters, with the rinsings of the still in the natural water of the charge (such portions of the residue as adhered to the walls of the vessel having been dislodged as completely as possible by gentle friction with a rubber or the ball of the finger), were carefully bottled and sealed, and the determination of the degree of concentration was left to be effected in the laboratory in a manner to be described later. A portion of the water represented by the concentrated sample was always reserved in the natural condition for examination.

For the determination of hydrogen sulphide special samples of from 600 cm^3. to 700 cm^3. were generally taken, and to each, if the water did not carry free sulphur, was added before corking and sealing a small amount of lead acetate in crystals. Doubtless it might have been well to fix the hydrogen sulphide similarly in the case of waters carrying free sulphur, having first separated this by filtration; but on the few occasions when that need arose the means of removing the sulphur were not at hand. In these cases, therefore, the samples were simply bottled and sealed with care, and kept for examination in the laboratory.

Nearly all the waters examined were hot when the samples were

taken and not surcharged with carbonic acid. It was considered unnecessary, therefore, under the circumstances, to take a special sample for the determination of the carbonic acid and treat it in the field so as to fix that gas in insoluble form, but for this estimation reliance was placed upon the general sample which, as has been said, was corked and sealed with great care.

OPERATIONS IN THE LABORATORY.

The operations in the laboratory comprised the determination of the specific gravity of the waters and, in the concentrated samples at hand, the estimation of the following substances:

* Silicic acid.	Iodine.	Barium.
Titanic acid.	Fluorine.	Strontium.
* Sulphuric acid.	* Sulphur.	* Calcium.
Sulphurous acid.	* Hydrogen sulphide.	* Magnesium.
* Carbonic acid.	Copper.	Cæsium.
Nitric acid.	Lead.	Rubidium.
Nitrous acid.	* Arsenic.	* Potassium.
Phosphoric acid.	Antimony.	* Sodium.
* Boric acid.	* Iron.	* Lithium.
* Chlorine.	* Aluminum.	* Ammonia.
Bromine.	Manganese.	* Albuminoid ammonia.

In analyses for which the natural water alone was available those substances only were sought which are marked in the table with an asterisk (*).

The determination of what is known as the *total residue*, the amount of solid matter left upon evaporating a known amount of water, is usually regarded as desirable, if for no other reason than to serve as a control of the summation of the determinations of the individual constituents; but the complexity of these waters and the relations of the combined salts are such that it is not possible to arrive at the same end in two successive treatments by evaporation and desiccation of the residue. The action of free silica, which is an abundant constituent of the waters, is to set free during the process carbonic acid from the carbonates and boric acid from the borates; to magnify the tendency of the chlorides of calcium, magnesium, and lithium to exchange chlorine for oxygen, and, if the temperatures be pushed sufficiently high, to dehydrate the silica and to volatilize sulphuric acid. Furthermore, the extent of such action is variable and indeterminate. There is obvious reason, therefore, for the difficulty which we experienced in obtaining residues of constant composition; and similar obstacles, as we found practically, oppose the attempt to reduce the residue to a definite condition by evaporation and ignition with sulphuric acid in excess. By means of no device which occurred to us (and several lines of experimentation which need not be mentioned here were followed) were we able to apply, in any form, this general method of control. The proof

of the accuracy of our analytical work rests, therefore, upon the agreement of duplicate determinations.

For convenience in the matter of arrangement, we describe first those methods of analysis which were applied to waters in the natural condition; and the account of the treatment of concentrated waters follows. Methods for the determination of certain substances are described under both heads. For when the entire work was done upon the natural water the mode of examination was sometimes made, of necessity, by processes different from those which were applied in the examination of concentrated water; and under reversed conditions the converse was true. In some of the earlier analyses methods were employed which later experience taught us might be advantageously replaced by processes which were developed subsequently. In the account of the methods employed all of these are placed under the proper head; and in the statement of analyses mention is made, when there might be doubt of the particular method adopted.

TREATMENT OF NATURAL WATERS.

Specific gravity.—The figures which stand for the specific gravity of a water represent the weight of any volume of the water under consideration at 15.5° C. compared with the weight of the same volume of distilled water at the same temperature. The determinations were nearly all made with a Geissler bottle, fitted with a ground tubular stopper and cap, and a thermometer. In a few of the earlier determinations a bulb-apparatus similar in general principle, but wanting the immersed thermometer, was employed. The temperature of the water in the bottle was taken immediately after the final adjustment of volume, and the latter was effected instantly and without handling after the filled bottle had been permitted to stand a few moments to bring about an equal distribution of temperature. When the bulb-apparatus was employed the temperature of the water was taken before filling the bulb and after weighing, and the mean of the two readings was assumed to be the temperature of the water at the time when the volume was adjusted. The weight shown by the balance was taken as the weight of the water which would fill the apparatus at the temperature noted. The weight of the same volume of the water at 15.5° C. was calculated from the weight observed, upon the assumption that the co-efficient of expansion of the water under examination was the same as that of pure water. The rates of the value thus found to the value found by a similar treatment of pure water is the specific gravity at 15.5° C. It is obvious that, in order that the assumption of the identity of the co-efficients of expansion of the water under examination and of pure water may be the occasion of the least error, the observed temperature must be as near 15.5° C. as may be; and that the temperature of the balance-room should be not far from the same, in order that errors which may arise from changes of temperature in the water during the manipula-

tion, and from the establishment of air-currents in the balance-case may be less liable to occur. So far as we were able these sources of inaccuracy were guarded against, but the conditions under which the work was performed necessitated the application of corrections rather greater than we should wish. The figures which represent the specific gravity in the statement of the analyses are probably not accurate beyond the fourth decimal place.

Hydrogen sulphide and free sulphur.—Hydrogen sulphide in waters which did not carry free sulphur was determined in the special sample to which lead acetate had been added in crystals at the time of bottling. Before breaking the seal of the bottle a scratch was made upon the neck on the line of the meniscus of the water within, and the volume of the sample—usually about 600 cm^3—was determined subsequently with sufficient accuracy (the amount of hydrogen sulphide present being always trifling) by finding the volume of water necessary to fill the bottle to the mark. The precipitate which had been formed in the bottle by the addition of lead acetate was left undisturbed at first, and the supernatant liquid decanted as completely as possible. Then the precipitate was easily removed, and for the most part dissolved by means of a little sodium hydrate in solution, and the solution and remaining precipitate were added to the water previously decanted. At this point the lead sulphide showed itself, if any was present, and was collected without difficulty by filtering the alkaline liquid in which it floated through a felt of asbestos in a perforated crucible, in the manner described by one of us previously.[1] The felt and the adherent precipitate were transferred to a beaker, treated with potassium chlorate and hydrochloric acid to oxidize the sulphide, and the sulphuric acid thus formed was determined by precipitation as barium sulphate. From waters carrying free sulphur that element was separated by filtration. The residue, after washing sufficiently to remove the sulphates, was treated with hydrochloric acid and potassium chlorate, and the resulting sulphuric acid was determined as barium sulphate. The filtrate from the sulphur contained the hydrogen sulphide, if it was present in the sample, and this was removed by lead acetate and estimated in the manner described above.

Sulphurous acid.—The test for sulphurous acid was made in the case of a few waters which did not carry more than a trace of hydric sulphide by titrating 200 cm^3 of the water, acidified with sulphuric acid, with a standardized solution of potassium permanganate. In none of these was a reducing action found greater than was attributable to the action of the hydrogen sulphide and arsenic (assumed to be in the condition of arsenious acid) known to be present.

Sulphuric acid.—The sulphuric acid was precipitated from a known weight of water, after acidifying distinctly with hydrochloric acid and heating to boiling by means of barium chloride. After cooling and

[1] Am. Chem. Jour., vol. 1, 1879, p. 317.

settling, usually after twelve hours, the supernatant liquid was decanted as completely as possible from the precipitate and passed through an asbestos felt in a perforated crucible. The precipitate remaining in the beaker was boiled with a small portion of strong hydrochloric acid, and the latter was removed by evaporation on the water-bath. Treatment with hot acidulated water left the precipitate as pure as barium sulphate may be, and ready for collection upon the same felt through which the supernatant liquid had been poured. Thorough washing, ignition, and weighing completed the operation.

Nitric and nitrous acids.—In examining the waters as regards their contents in nitric and in nitrous acids a modification of the indigo method was followed. The action of these acids upon indigo is known not only to be variable with the conditions of dilution, temperature, and the proportion of sulphuric acid added, but also to be dependent upon the order in which the solution of indigo, the sulphuric acid, and the nitrous or nitric acid are intermixed. On this account great care was taken to secure uniformity of treatment of the standard solutions and the water under the test. For preliminary testing a portion of water was reduced by evaporation to a volume of 50 cm^3. cooled to the temperature of the air, introduced into an Erlenmeyer flask, and mixed with an equal volume of strong sulphuric acid. To the mixture the solution of indigo was added until a distinct tinge of green became visible. In this manner the amount of the solution of indigo from which a given amount of the water under test would discharge the color became known approximately. For the exact test the portion of water, after evaporation and cooling, was brought to a volume which was less than 50 cm^3. by an amount equivalent to the volume of the solution of indigo used in the preliminary test. To the portion thus prepared were added 50 cm^3. of strong sulphuric acid at once, and the solution of indigo as rapidly as the catching of the exact point at which the tinge of green appeared would permit. At the instant of coloration the flask with its contents was placed in a bath of paraffine heated to 140° C. The volume of the solution of indigo which had been added was noted and, if at the end of five minutes' heating in the bath the tinge of color was still visible, this volume was taken as the measure of the nitrates and nitrites in the water. If, on the other hand, the color vanished during the heating, it was reproduced by the addition of more indigo, and the digestion in the bath at 140° C. was prolonged during another interval of five minutes.

This mode of treatment was repeated until the coloration was permanent during the interval of digestion. The total volume of the solution of indigo employed was recorded, and its value in terms of nitric acid determined in the manner to be described.

As Warrington has shown,[1] the oxidizing power of nitric acid upon *indigo decreases* as the dilution of the solution in which the action takes

[1] Jour. Chem. Soc. London, 1879, p. 578.

place increases. It is plain, therefore, that in order that the exact value of the volume of the indigo solution employed in the test may be known, the amount of nitric acid needed to discharge the color from an equal amount of the same solution under the conditions of the test must be determined. To effect this determination we made use of a solution of potassium nitrate of known strength, and found by experiment the amount of it which, mixed with 50 cm^3. of strong sulphuric acid, with water enough to bring the final volume to 100 cm^3., and with the amount of the solution of indigo employed in the test, was just adequate to discharge all color excepting the faint characteristic tinge which must remain unchanged after five minutes' heating. The oxidizing power of the nitrates and nitrites in the water is exactly measured by the amount of nitric acid in the quantity of the standard nitrate solution which is required to produce the end-reaction. The solution of potassium nitrate which we used contained 0.0001 g. to 1 cm^3. The mode of manipulation which we adopted keeps the proportion of strong sulphuric acid added to the mixture (excepting the preliminary tests) always the same, and consequently the heat generated in the reaction is the same always. The order in which the re-agents are brought together is the same in all cases, and sources of inaccuracy due to the variability of the action of nitric acid with the degree of dilution are eliminated.

Carbonic acid.—The greater number of the waters with which we have had to deal were hot when the sample was taken, and not surcharged with carbonic acid. In view of the circumstances under which the waters were collected it was thought that a portion of the general sample, which was carefully sealed, might be made to serve the purpose of determining the carbonic acid contained in the water, instead of portions taken specially for that end and treated in the field with a mixture of ammonia and calcium chloride to fix the carbonic acid gas. Accordingly dependence was placed upon the large general sample for this estimation. The presence of free silica in the waters and the complexity of composition place so great an obstacle in the way of determining the *free carbonic acid* that the attempt to make the estimation was not undertaken. The method which we adopted for the determination of the *total carbonic acid* is that well-known process which rests upon the boiling of the acidified liquid and the absorption and weighing of the gas evolved. The apparatus which we employed, differing somewhat from that in ordinary use for this purpose, is shown in Fig. 1. It consisted essentially of a flask in which to boil the water, a cooler to return the condensed steam to the flask, a U tube filled with anhydrous cupric sulphate to intercept traces of hydrochloric acid which might escape condensation in the cooler, a second U tube charged with calcium chloride to dry the gas, potash bulbs to retain the carbonic acid, and two tubes filled with calcium chloride, one of which was to retain moisture carried over from the potash bulbs and was weighed with

them, the other serving to protect the weighed tube from the action of the external air. Through the rubber stopper of the flask passed the tube of a separating funnel, the end of the condensing tube, and a tube which connected the interior of the flask with the system of bottles and scrubbing tower, which furnished at will and under slight pressure a supply of dry air free from carbonic acid.

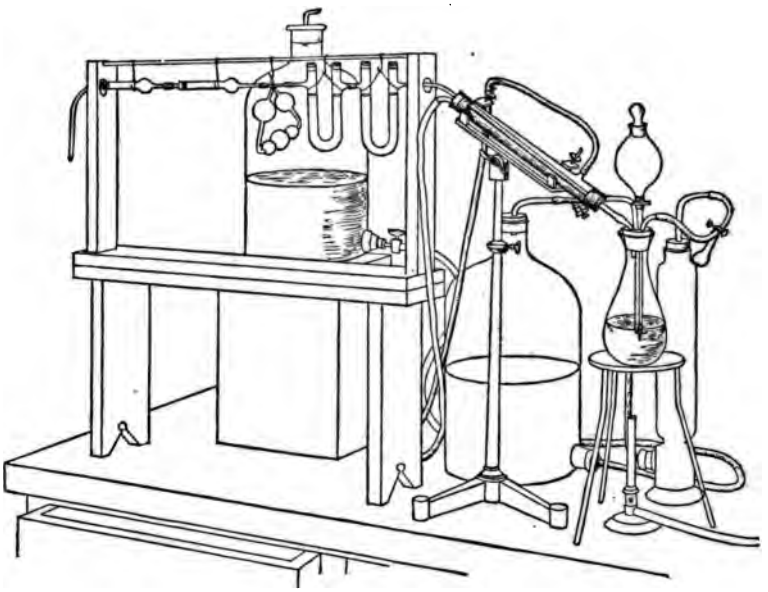

FIG. 1.—Apparatus for the estimation of carbonic acid.

Before beginning the operation of determining the carbonic acid in a water the atmospheric air was expelled from the apparatus and replaced by pure air free from carbonic acid. The stop-cock in the funnel tube and the connection with the aspirator having been closed, the water started through the cooler, and the joint broken between the potash bulbs and the drying tube immediately preceding it, a few cubic centimeters of distilled water were put into the flask and boiled. The steam generated drove the air from the flask, and that remaining in the tubes was swept forward by pure air admitted from the aspirator. The outer opening of the tube at the end of the line was closed, the source of heat removed, and the flask allowed to fill with air from the aspirator. The whole apparatus having been filled thus with air free from carbonic acid, the water to be examined—we found 200 g. to be a convenient amount—was introduced into the flask through the funnel tube and followed by a little boiled water and a sufficiency of sulphuric acid, care being taken to exclude the outer air during the operation. The connection between the line of drying tubes and the absorption bulbs was re-established, the liquid in the flask was brought to the boiling point, and, to secure *constant and quiet* ebullition as well as to aid in transferring the carbonic *acid from the* flask to the absorption bulbs, a current of pure air was

sent slowly through the boiling liquid which covered the end of the aspirating tube and that of the funnel tube. At the end of half an hour the burner was removed from under the flask and the apparatus was permitted to cool during another half hour, the current of air being kept in motion through it. The difference between the weights of the potash bulbs, with the drying tube which accompanies them, before and after the operation, was taken to be the weight of carbonic acid absorbed, and the *total carbonic acid* of the portion of water examined.

When the water under examination contained hydrogen sulphide, a little cupric sulphate was introduced before acidifying into the portion which was to serve for the determination of carbonic acid.

Arsenious acid and boric acid.—To the portion taken for analysis—usually 500 g.—hydrochloric acid was added in distinct excess, the temperature of the liquid was raised to 70° C., and the source of heat having been removed, hydrogen sulphide gas was introduced in a gentle current for several hours. The precipitation of the arsenious sulphide began at once, but the action of the precipitant was continued to insure completeness. The precipitate was collected upon an asbestos felt, washed, and dissolved in fuming nitric acid. The solution in nitric acid was evaporated to dryness, the residue was dissolved in hydrochloric acid, and from this solution, made strongly ammoniacal but kept small in volume, the arsenic was precipitated by the addition of the magnesium chloride mixture and brisk agitation. The precipitated ammonium-magnesium arsenate was allowed twelve hours in which to settle and was then transferred by means of the mother liquor, without the use of other liquid, to a perforated crucible carrying an asbestos felt, washed thoroughly with the mixture of one part of ammonia to three of water, usually employed for this purpose, but with the sparing use of the washing material which this mode of filtration permits, dried carefully, ignited gently at first, and at a low red heat afterward, in an atmosphere of oxygen. The great faults of this process, originally Levol's, have been the solubility of the precipitate in the mother liquor and, more especially, in the ammoniacal wash water, and the difficulty in drying or igniting the precipitate collected on paper. These sources of inaccuracy vanish, however, so completely with the use of the asbestos filter and due care in keeping the volume of mother liquor and the washings small, that the filtrate, freed from ammonia, acidified and charged with hydrogen sulphide, fails to yield arsenious sulphide. As a test for the presence of arsenic the method has enjoyed an excellent reputation, and in the form in which we have made use of it we believe it to be exact.

The filtrate from the precipitate of arsenious sulphide, containing all the boric acid, was nearly freed from hydrogen sulphide by the transmission of air, and the chlorine, with residual traces of hydrogen sulphide, was removed by treatment with silver nitrate and filtration. The filtrate from the precipitated sulphide and chloride was treated with sodium

hydrate, in quantity a little more than sufficient to precipitate the excess of silver, as completely as may be. The whole was evaporated until the precipitate took on a compact and granular form, then filtered, and the filtrate was evaporated nearly to dryness. The residue was treated with nitric acid, first just to acidity, and then with a sufficient (measured) amount to make it certain that the boric acid was entirely free. The concentrated solution of the nitrates, nitric acid, and boric acid was drenched with methyl alcohol to precipitate the first and dissolve the last. The solution of boric acid was quickly separated from the precipitate by means of the vacuum filter, and the residue washed sufficiently with methyl alcohol. When much boric acid is present the precipitated nitrates should be dissolved in water and the process of precipitation with methyl alcohol repeated; but when small quantities are dealt with, as was the case in the most of our work upon these waters, a single treatment leaves no boric acid in the residue. From the solution in methyl alcohol, the boric acid was separated and its amount estimated by a method devised by one of us and described elsewhere in full.[1]

This process consists essentially in distilling to dryness the solution in methyl alcohol, containing free nitric acid and nitrates, and treating

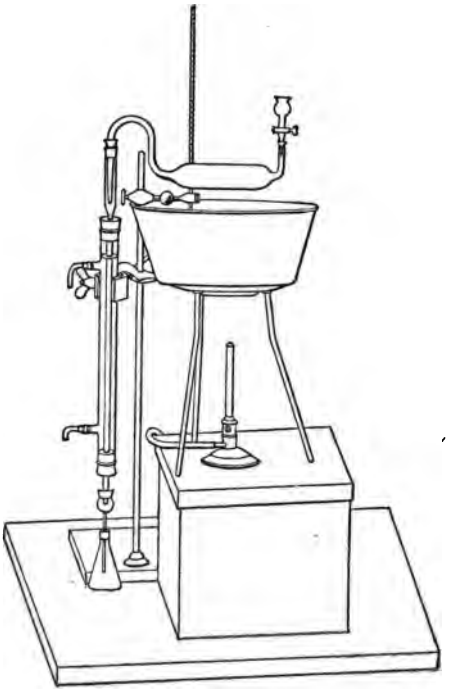

Fig. 2.—Apparatus for the estimation of boric acid.

[1] *Bulletin of the U. S. Geological Survey, No. 42. Am. Chem. Jour., vol. 9, p. 23.*

the residue by successive drenchings with methyl alcohol and distillations. The distillate, carefully protected, contains at the end of the operation all the boric acid, and this is fixed as calcium borate by the evaporation of the distillate over lime. The difference between the weight of ignited lime and the weight of the same after having been submitted to the action of the alcoholic solution and ignition is the weight of boric anhydride in the solution.

The distillation was effected by means of an apparatus which consists of retort, condenser, and bath for heating (Fig. 2). For the last a bath of paraffine is on the whole most convenient. The condenser is set vertically to facilitate changing the level of the retort within the bath, and to secure at the same time continued and thorough washing of the tube by its own condensations. The retort, somewhat like the well-known drying tube of Liebig in general shape, is easily made of a pipette by bending the tube at one end to a right angle, at the other to a goose-neck, as shown. To the former end is fitted, by a rubber stopper or section of tubing, a glass funnel-tube provided with a stop-cock; the end of the goose-neck passes tightly through a rubber stopper in the upper end of the condensing tube. This is essentially the apparatus; but it is convenient to attach, to receive the distillate, a small Erlenmeyer flask, which moves with the condenser and is joined to it, in the manner indicated in the figure, by means of a thistle tube and a rubber stopper grooved to permit the free passage of air. In carrying out the distillation the liquid is introduced into the retort either by the funnel tube or previous to its insertion, the glass stop-cock is closed, the water started through the condenser, and the retort lowered into the hot paraffine, care being taken to begin the operation with the retort not more than half full and so inclined that only the rear dips below the surface of the bath. If the precaution to heat the retort at the start in this manner be overlooked it may sometimes happen that the sudden and violent expulsion of air through the liquid will carry portions of it bodily into the goose-neck and even into the condenser. With this point considered, the remainder of the operation presents no difficulty and requires little care. The size of the retort may be suited, of course, to the particular case in hand, but for most purposes a pipette of 200 cm^3. capacity makes a retort of convenient dimensions, neither too large for the distillation of small charges nor too small to permit the treatment of 100 cm^3. of liquid comfortably. The tube of the goose-neck should be wide enough to prevent the formation of bubbles in it; 0.7 cm. is a good measure for the interior diameter. It is of advantage to heat the bath to a point considerably above the temperature at which the liquid to be distilled boils—something between 130° C. and 140° C. does very well for water, and is not too high for methyl alcohol—and under such circumstances, and when the retort is entirely submerged, it often happens that evaporation takes place with extreme rapidity from the surface of the liquid *in perfect* quiet and without actual boiling.

Experiment showed that six successive treatments by drenching with 10 cm^3. of methyl alcohol and distillation to dryness were more than adequate to remove 0.2 g. of boric anhydride entirely from a residue containing 2 g. of sodium nitrate; but, in order to break up the crusted residue, which by its insolubility in the alcohol might effect to some extent the protection of the boric acid from the action of the alcohol, it was found best to introduce and evaporate 2 cm^3. of water between the second and third, and again between the fourth and fifth distillations. In most of the cases with which we were concerned in the work upon these waters four treatments by drenching and distilling, with one intermediate moistening with water, were entirely sufficient to volatilize the boric acid; but in every case the residue was examined for boric acid by the exceedingly delicate turmeric test, taking care to first oxidize nitrites by means of bromine, and to expel the last before applying the test.

When the solution of boric acid in methyl alcohol is put over lime and evaporated at once some volatilization of the boric acid is apt to take place; but a short period of digestion—from five to fifteen minutes—is sufficient to fix the boric acid completely.

To secure the proper exposure before evaporation, with the least delay, the lime which is to retain the boric acid, first ignited in the crucible in which the evaporation is to be made subsequently, is transferred to the receiving flask attached to the condenser before the distillation is begun, and so has opportunity to exert its action upon the boric acid as the distillation progresses. At the end of the distillation the distillate, containing the alcohol, boric acid, nitric acid, and lime, is transferred again to the crucible, evaporated to dryness at a very gentle heat, and ignited to a constant weight over the blast lamp. The greatest care is to be taken to secure similarity of conditions under which the crucible and lime are weighed before and after ignition, and definite periods of cooling before weighing—ten minutes is a suitable time—should be allowed to pass, in order to eliminate, as far as possible, the effect of atmospheric condensation upon the large surface of platinum. The tendency of the process is to yield figures slightly larger than the truth, as was shown in the test analyses which are given in the full description of the process, to which reference has been made. In distilling 0.2 g. of boric anhydride and fixing it in 1.5 g. of calcium oxide, the mean error was shown to be about 0.0010+g. In the work upon the waters parallel determinations rarely differed by more than that amount.

Chlorine (with bromine and iodine).—The precipitation of chlorine, together with bromine and iodine, was usually effected without difficulty by treating the weighed portion of water—from 100 g. to 500 g., according to the circumstances—with nitric acid to a slightly acid reaction and silver nitrate in excess, directly and in the usual manner, excepting that

the operation was effected in the cold and that the whole was allowed to stand quietly in the dark for several hours to secure perfect subsidence of the precipitate. In only one or two cases did the silica, which the waters carry abundantly, give rise to trouble in the precipitation. In such cases comparative tests were made as just described upon portions treated previously with an excess of pure sodium hydrate, it having been noticed that certain very siliceous waters, which of themselves very quickly filled the pores of the filter with an invisible coating of silica, could be made to filter with rapidity by first treating them with sodium hydrate in excess, and then with nitric acid to slight acidity. Treatment with acid alone did not bring about the desired condition of the silica. In the case of the water of the Coral Spring the proportion of silica is so great and its character such that to secure satisfactory results we were obliged to convert the silica to hydrofluosilicic acid, by the addition of hydrofluoric acid and nitric acid, before precipitating the silver salt. The silver chloride (including the bromide and iodide) was collected upon asbestos in a perforated crucible, dried directly over the free flame of a Bunsen burner turned very low and at a temperature below its melting point, and weighed. In the case of waters containing hydrogen sulphide in quantity precipitable by silver nitrate the portion for analysis was rendered ammoniacal before the addition of the silver salt, and the precipitated silver sulphide was filtered off. The silver salts of the halogens were then precipitated from the filtrate by nitric acid, and the process was completed as described.

Silica, iron and aluminum, calcium, and magnesium.—A single weighed portion of water served for the determination of the silica, iron and aluminum, calcium and magnesium. The water was acidified with hydrochloric acid, evaporated to dryness in platinum over the water-bath, again acidified and again evaporated. The residue was digested with hot water containing a little hydrochloric acid, and the solution was filtered from the residue of silica, which was ignited in platinum and tested as to its purity in the usual manner with hydrofluoric acid.

In the filtrate ammonia, in the slightest excess, precipitated ferric and aluminic hydrates from the boiling solution, and these were collected, ignited, and weighed as oxides in the usual manner. The lime was thrown out of the hot ammoniacal filtrate by ammonium oxalate, and the calcium oxalate filtered off after standing twelve hours in the cold. When the amount precipitated exceeded a few milligrams it was dissolved in hydrochloric acid, reprecipitated by ammonia and ammonium oxalate and collected upon a filter, the filtrate from the second precipitation being added to that from the first. The calcium oxalate was dried, ignited, and weighed as calcium oxide.

The filtrate (or the united filtrates) from the calcium oxalate was evaporated in platinum, and the residue was gently ignited to destroy the ammonium oxalate—which tends to delay the precipitation of the magnesia if permitted to remain in the solution—and dissolved in hy-

drochloric acid. From this solution the magnesia was precipitated in the usual manner by microcosmic salt and ammonia, and after standing twelve hours or more, the phosphate was collected upon asbestos in a perforated crucible, washed with the mixture of one part of ammonia to three of water, commonly used in the process, moistened at the end of the washing with a strong solution of ammonium nitrate in ammonia, ignited for a moment to redness, and weighed as the pyrophosphate.

Sodium, potassium, and lithium.—In some of the earlier work only sodium and potassium, of the alkalies, were determined in the natural water, and for the determination of the lithium portions of the concentrated water were treated by the method which will be referred to later. In the greater number of cases the same portion of the natural water served for the determination of lithium as well as sodium and potassium. The portion for analysis was acidified in platinum with hydrochloric acid and evaporated to dryness. The residue was extracted with hot water slightly acidulated with hydrochloric acid, the solution was separated from the precipitated silica by filtration, and to the filtrate was added, with care to secure a sufficiency and yet to avoid a great excess, barium hydrate made from the nitrate, itself purified by precipitation by nitric acid. Filtration separated the precipitated hydrates of aluminum, iron, and magnesium, with barium sulphate; and from the filtrate ammonium carbonate and ammonia precipitated, upon boiling, nearly the whole of the barium and calcium as carbonates. The filtrate from the precipitated carbonates was evaporated to dryness, and the residue was gently ignited to remove ammonium chloride, treated with hydrochloric acid, freed from the excess of acid by evaporation on the water-bath to dryness, dissolved in a very small amount of water, and treated again with a few drops of the solution of ammonium carbonate and ammonia. This treatment usually results in the precipitation of traces of barium carbonate which have previously escaped removal by the similar treatment of the larger volume of liquid. The filtrate from this last slight precipitate was again evaporated and treated as before; and, in case any further precipitation took place, the process was repeated until the purification was complete. Usually, however, the first precipitation in the larger volume of liquid and the second treatment in the solution reduced to small bulk are together sufficient to remove the barium carbonate completely. The filtrate from the last precipitate was evaporated in a weighed platinum dish, and the residue, consisting of the chlorides of sodium, potassium, and lithium, was dried, gently ignited, and weighed.

From the mixed chlorides the lithium salt was separated by a process which, devised by one of us during the progress of the work and described elsewhere in full,[1] needs but brief outlining in this place. To the concentrated solution of chlorides amyl alcohol is added and heat is applied, gently at first to avoid danger of bumping, until, the water

[1] *Bulletin of the U. S. Geological Survey*, No. 42, p. 73; Am. Chem. Jour., vol. 9, p. 33.

disappearing from solution and the point of ebullition rising and becoming constant for some minutes at a temperature approximately that at which the alcohol boils by itself, the chlorides of sodium and potassium are deposited, and the lithium chloride is dehydrated and taken into solution. At this stage of the proceeding the liquid is cooled, a drop or two of strong hydrochloric acid being added to reconvert traces of lithium hydrate possibly in the deposit, and the boiling is continued until the alcohol is again free from water. If the amount of lithium chloride present in the mixture of salts is small it is now found in solution; the chlorides of sodium and potassium, excepting the traces for which correction will be made subsequently, are in the residue; and the separation may be effected by filtration and the washing of the residue with amyl alcohol previously dehydrated by boiling. If, on the other hand, the weight of lithium chloride present exceeds ten or twenty milligrams it is advisable, though not absolutely essential to the attainment of fairly correct results, to decant the liquid from the deposit, wash the latter with a little anhydrous amyl alcohol, dissolve in a few drops of water, and repeat the separation by boiling in amyl alcohol.

The filtrates, first measured apart, are united with the washings and evaporated to dryness, and the residue, treated with sulphuric acid in excess, ignited gently at first and finally to the fusing point, is weighed as the neutral lithium sulphate, containing traces of the neutral sulphates of sodium and potassium. From the weight thus found the subtraction of 0.00109 g. for every 10 cm^3. of filtrate exclusive of washings makes the proper correction for the amounts of the sodium and potassium salts present, and the residual weight represents the pure lithium sulphate. In cases where the precipitate consists solely of sodium chloride, the correction upon the weight of the sulphate is 0.00050 g.; when potassium chloride constitutes the residue the correction amounts to 0.00059 g. for every 10 cm^3. of filtrate. The alcohol used in washing has, within reasonable limits, no appreciable solvent effect upon the precipitate.

The precipitate, consisting entirely of sodium chloride and potassium chloride, is ready for the balance after drying a few minutes directly over a flame turned low, if the filtration is effected by means of asbestos in the perforated crucible; if paper is used as the filtering medium, after the solution of the precipitate, the evaporation of the solution and the gentle ignition of the residue. The weight of the insoluble chlorides actually obtained is corrected for the solubility of the salts in amyl alcohol by adding 0.00092 g. for every 10 cm^3. of amyl alcohol in the filtrates, exclusive of washings; 0.00041 g. of this representing the sodium chloride dissolved, and 0.00051 g. the potassium chloride. With due attention to the reduction of volume of the residual alcohol before filtering the correction may be held easily within narrow limits.

In applying this method to the analysis of the waters of the Yellowstone Park the practice of reducing the volume of amyl alcohol to about 15 cm^3. before filtering was followed uniformly. The corrections, therefore, were always the same, and amounted to an addition of 0.0007 g. to the apparent weight of sodium chloride, 0.0008 g. to that of potassium chloride, and a subtraction of 0.0017 g. from the weight of lithium sulphate indicated by the balance. In many cases the lithium present in the waters, though capable of detection by the spectroscope, amounted to so little in the portions devoted to its determination that the application of the correction left nothing to be called lithium sulphate. In such cases the lithium is counted as a "trace."

From the mixture of sodium chloride and potassium chloride the potassium salt was separated as potassio-platinic chloride. The chlorides were dissolved in a small amount of water, platinic chloride was added in solution, in quantity considerably in excess of the amount necessary to effect the conversion of all the potassium and sodium present to the double platinum salts, and the mixture evaporated on the water-bath to the point at which the residue becomes pasty if removed from the bath and allowed to cool. The crust thus formed was drenched with alcohol of 80 per cent., digested in the cold until thoroughly disintegrated, filtered off on an asbestos felt, washed with alcohol of 95 per cent., dried at a gentle heat, and weighed.

The lithium and potassium having been thus found directly, the sodium is given, in the form of the chloride, by the difference between the sum of the lithium and potassium chlorides and the total weight of the three chlorides; or, by the difference between the weight of potassium chloride found and the weight of the chlorides of potassium and sodium found (the proper correction having been applied) after the separation of the lithium. It may be urged against the former plan that to bring the three chlorides to a definite condition for weighing is a difficult undertaking in view of the great tendency of lithium chloride to exchange chlorine for oxygen in the presence of water. Our experiments indicated, however, that under repeated treatments by moistening and ignition the mixed chlorides did not change in weight materially, and we are disposed to attribute the result in part to the protective influence of the sodium and potassium salts upon the relatively small amount of lithium chloride, and in part to the care taken to secure thorough drying at a low temperature previous to the gentle ignition. In our work upon the waters we weighed the three chlorides together and found the sodium chloride by deducting from this weight the weights of potassium chloride and lithium chloride deduced by analysis.

A weak point in the process which we have employed in the determination of the alkalies would seem to be found in the separation of the magnesia by means of barium hydrate. In connection with this subject it is of interest to note that in the greater number of waters *magnesia was present* only in inconsiderable quantity, and further, that in

the case of those in which it did appear in appreciable amounts the examination of the solution of the lithium sulphate, after the separation by amyl alcohol, failed to indicate the presence of magnesia in amount sufficient to be precipitable by microcosmic salt in an ammoniacal solution and under the usual conditions of the test, though this would be the place in which magnesia should appear if it had escaped removal from the chlorides. We are constrained to believe, therefore, that the process of separation which we adopted was exact within reasonable limits.

Ammonia and albuminoid ammonia.—The determination of ammonia was effected in the usual manner by distilling a measured portion of water with sodium hydrate, and nesslerizing the distillate. A second portion of water was distilled with sodium hydrate and potassium permanganate, and the distillate was nesslerized. The former process gives the combined ammonia present in the water; the latter the total ammonia, which includes, beside the ammonia existing as such in combination, that ammonia which is developed from other nitrogenous compounds by the action of the permanganate. The difference between the figures of the two processes is the albuminoid ammonia, so called. The composition of these waters renders them peculiarly liable to boil explosively, and some difficulty was experienced at first in the distillation; but the apparatus which is described in the paragraph on the determination of the boric acid proved to be of service in this case also, and made the determination practicable. The Nessler solution was very delicately adjusted, and the tests were made in small tubes and carried to the limit of 0.000001 g.

TREATMENT OF CONCENTRATED WATERS.

In the examination of the concentrated waters the whole sample was evaporated to dryness, and the residue thus left was extracted with hot water. It is usual in treating concentrated waters to add sodium carbonate during the evaporation, and to wash the residue until the washings cease to show an alkaline reaction. Four of the waters of which we had concentrated samples were, however, so alkaline of themselves that the addition of sodium carbonate was superfluous, and all were so siliceous that to wash the residue of evaporation until it was free from alkali was a matter of the greatest tediousness and difficulty. We found it best and sufficient to wash only to the vanishing point of the spectroscopic reaction for lithium in the washings. In this manner the separation of the greater part of the silica with the insoluble constituents of the water was effected without an entirely unreasonable expenditure of time and effort. The filtrate and washings were thoroughly mixed and made up to a definite weight. The residue was kept by itself for separate treatment.

The filtrate should contain the bromine, iodine, boron, arsenic, antimony; the copper, lead and tin, which can be present in the waters

only in traces; the lithium, cæsium, rubidium, thallium, and part of the silicon and aluminum. The precipitate should contain the titanium, phosphorus, fluorine, iron, manganese, barium, strontium, calcium, magnesium, with the remainder of the aluminum and silicon.

STRENGTH OF THE CONCENTRATED WATERS.

The degree to which the concentration of the waters had been carried in the field was fixed by the determination of the total amount of halogens in a weighed portion of the extraction of the residue of evaporation. This portion was diluted, acidified with nitric acid, treated with silver nitrate until the precipitate ceased to form, and the last was collected on asbestos in a perforated crucible, dried (over the free flame of a Bunsen burner turned low) at a temperature considerably below its melting point, and weighed. Determinations of this sort were made in duplicate. Knowing the weight of the silver salt thus found and the weight of the same precipitable from a known weight of the natural water, the exact value of the concentrated water, in terms of the natural water which it represented, became known.

TREATMENT OF THE RESIDUE.

Fluorine.—The residue, dried by gentle heating, with the ash of the filter employed in separating and washing it, was placed in a retort of the pattern described in the section treating of the determination of boric acid in the natural water, drenched with strong sulphuric acid, and heated to 150° C., while a slow current of dry air was forced through the emulsion and thence directly into a U tube partly filled with dilute ammonia. The fluorine contained in the water should appear in the residue as calcium fluoride, should be volatilized as silicon fluoride by the action of the sulphuric acid, and, if present in more than very small amounts, should be indicated by the precipitation of silica in the U tube containing ammonia. Proceeding in this manner we found in the waters which we examined no fluorine; and on treating the ammoniacal liquid of the U tube according to the method of Berzelius, with zinc oxide dissolved in ammonia, evaporating until the solution ceased to evolve ammonia, filtering, adding to the filtrate calcium chloride followed by sodium carbonate, boiling, igniting the precipitate and extracting it with acetic acid, we were not able to detect a residue of calcium fluoride; nor in the zinc oxide precipitated by the expulsion of the ammonia dissolving it could we discover silica.

Barium and strontium.—The contents of the retort were transferred to platinum, treated with hydrofluoric acid (purified by redistillation) in sufficient amount to volatilize all silica, and evaporated to dryness with a little sulphuric acid. To insure thoroughness of action this process of treatment was repeated. The residue was fused with sodium carbonate and the melt was extracted with hot water containing a few drops

of alcohol. The precipitate was separated from the solution by filtration and digested with hot dilute acetic acid, which should dissolve the barium, strontium, calcium, and magnesium carbonates. The solution in acetic acid, separated by filtration from the portion unacted upon, was nearly neutralized with ammonia, and to it was added in solution an amount of ammonium sulphate equal to fifty times the weight of the alkaline earths present, the whole being permitted to stand quietly twelve hours. By this treatment barium and strontium should be precipitated as sulphates, while calcium and magnesium should remain dissolved. The sulphates of barium and strontium may be separated afterward by digestion during twelve hours (at the ordinary temperature and with frequent stirring) in ammonium carbonate, the decantation of the supernatant liquid, the repetition of the treatment with ammonium carbonate, and, finally, the action of hydrochloric acid upon the residue—the strontium carbonate dissolving and the barium sulphate remaining insoluble in this acid. This mode of separating the barium and strontium was not actually applied in our work, inasmuch as we obtained from the quantities of water with which we had to deal no precipitate by ammonium sulphate, and it is mentioned only for the purpose of completing the scheme of analysis.

The solution which had been treated with ammonium sulphate to precipitate barium and strontium was preserved for subsequent examination for manganese.

Phosphoric acid.—The extract of the fusion in sodium carbonate was acidified with nitric acid, evaporated to small bulk, and from it the phosphoric acid was precipitated in the usual manner as a phosphomolybdate of ammonia. The precipitate, after standing twelve hours, was separated by filtration through a felt of asbestos in a perforated crucible, washed with the precipitant, and dissolved in ammonia. From this solution the phosphoric acid was precipitated by the magnesium and ammonium chloride mixture, and the ammonio-magnesium phosphate was filtered off on asbestos, washed with dilute ammonia (one part of ammonia to three of water), moistened with ammonium nitrate in ammonia, dried, ignited at a red heat, and weighed as magnesium pyrophosphate.

Manganese.—The residue left, after the extraction of the fusion in the sodium carbonate with water containing a little alcohol and the treatment with acetic acid, was fused again in a little sodium carbonate, the melt was dissolved in the crucible by heating with strong sulphuric acid, and this solution was poured into cold water. In this manner was obtained a solution containing the titanium and iron, and a part of the aluminum and manganese. From it all these elements, excepting the last, were precipitated by adding ammonia to an alkaline reaction followed by acetic acid to faint acidity, and boiling. The precipitate was kept for examination later. The solution was mixed with that which had been treated with ammonium sulphate in the test for barium and

strontium, and to the mixture, heated on the water bath, were added ammonia in excess and bromine water. The precipitate thus obtained was ignited and weighed as Mn_3O_4, it being so trifling that solution and reprecipitation as the phosphate was unnecessary.

Iron.—The precipitate of ferric, titanic and aluminic hydrates was fused in a little sodium carbonate, the fusion was dissolved in strong sulphuric acid, this solution poured into cold water, and the dissolved iron, titanium, and aluminum were separated as follows, by a process devised by one of us and described fully elsewhere.[1] Tartaric acid, amounting to three times the weight of the oxides of iron, aluminum, and titanium present, was added to the solution, which was then made faintly ammoniacal and submitted to the action of a current of hydrogen sulphide. The precipitated ferrous sulphide was filtered off (care having been taken that the solution should still be alkaline before filtering), washed with hot water sufficiently but expeditiously, dissolved in hydrochloric acid, and the iron, first oxidized by bromine, was precipitated by ammonia and weighed as the oxide.

Titanic acid.—The filtrate from the ferrous sulphide was acidified strongly with sulphuric acid, heated to the boiling point, and treated with potassium permanganate until its characteristic color appeared. The final products of the action of the permanganate upon the tartaric acid are carbonic acid and water, but formic acid appears as an intermediary step in the oxidation. During the first action of the permanganate its conversion to manganous sulphate is rapid, but with the development of formic acid there takes place by its action upon the permanganate freshly added a precipitation of a brown hydrate of manganese which, redissolving readily so long as tartaric acid remains, yields only slowly to the further action of the formic acid. When, therefore, manganic hydrate appears abundantly in the boiling solution and does not dissolve perceptibly one may be reasonably certain that the conversion of the tartaric acid to at least the intermediary stage has been accomplished; but for the sake of greater security, the addition of the permanganate may be continued until the appearance of its color. When the amount of tartaric acid in the solution is known, as should be the case always, a simple mode of proceeding is, perhaps, to employ for the oxidation the amount of permanganate theoretically required. A weight of potassium permanganate amounting to two and a half times the weight of the tartaric acid to be destroyed is sufficient to carry the oxidation to the ultimate limit, providing there be no deposition of a manganic hydrate.

The residual permanganate and the insoluble hydrate were reduced and dissolved by the addition of a little ammonium bisulphite to the acid solution, and, the excess of sulphurous acid having been boiled off, acetic acid was added to the clear solution in quantity sufficient to make

[1] *Bulletin of the U. S. Geological Survey, No. 27, p. 16; Am. Chem. Jour., vol. 7, 1885–'86, p. 283.*

the amount of the absolute acetic acid present from 7 to 11 per cent. by volume; enough sodium acetate was introduced to fix all the sulphuric acid as sodium sulphate, and the solution was boiled. If titanium is present it is precipitated under these conditions, while the aluminum remains dissolved. If the quantity of the precipitate thus obtained is considerable, it should be filtered from the liquid in which it floats and purified from the traces of manganese which it may carry, by fusion in a small quantity of sodium carbonate, the solution of the melt in sulphuric acid, and reprecipitation by ammonia.

In the waters which we examined we found no precipitate of titanic hydrate at the point in the process where it should appear were titanium present.

TREATMENT OF THE AQUEOUS SOLUTION.

The aqueous solution, its degree of concentration having been determined in the manner already described, was divided into five portions. Two of these were taken for the determination of bromine, iodine, lithium, cæsium, rubidium, and thallium, in duplicate; two for the determination in duplicate of arsenic, antimony, tin, copper, lead, and boron; and the remaining portion was reserved to be used in an emergency.

Iodine and bromine.—The portion for the determination of the elements of the former group was weighed and evaporated to a pasty condition. The residue was thoroughly extracted with strong alcohol, treated with water reduced again nearly to dryness, and again extracted with alcohol. The extract was evaporated after the addition of a drop or two of a strong solution of sodium hydrate, and this residue was extracted with alcohol like the former residue. The residues of the extractions with alcohol were kept for subsequent treatment. The alcoholic solution containing presumably all the iodine and bromine, with a small proportion of the chlorine originally in the water, was evaporated to dryness, and the solution of the residue in water was acidulated with sulphuric acid mixed with a solution of ferric sulphate introduced into a retort of the pattern previously described and figured in connection with the determination of boric acid in the natural waters, and distilled. The distillate was collected in a U tube attached to the condensing tube and sealed with carbon disulphide and water. If iodides are present in the retort to the minutest degree the iodine is set free as such, its characteristic color appears in the seal of carbon disulphide, and its amount may be determined by titration in the usual manner with sodium hyposulphite.

In the waters which we examined iodine was not present in sufficient quantity to appear in the test of the amounts at our disposal.

To the liquid remaining in the retort after the distillation had been prolonged sufficiently to insure the complete volatilization of the iodine a few crystals of potassium permanganate were added, and the distilla-

tion was continued. This distillate was collected as before in a U tube joined to the condenser, but the seal was made with chloroform and water. At the beginning of the operation the seal of the U tube showed in most cases the characteristic color of bromine, but this was discharged before the end of the operation by the excess of chlorine and replaced by the color of the latter. The contents of the U tube were transferred to a beaker and treated with pure sodium hydrate and zinc, and from the solution of sodium bromide and chloride thus obtained the silver salts were precipitated by silver nitrate, in the usual manner, after acidifying with nitric acid. The silver bromide and chloride thus precipitated were collected together upon asbestos in a perforated crucible, dried, weighed, and dissolved in potassium cyanide. From the cyanide solution the silver was deposited by electrolysis, according to the process described elsewhere by one of us for the indirect estimation of bromine in the presence of chlorine.[1] In this manner we obtained the weight of the mixture of silver chloride and silver bromide, and the weight of the silver contained in the mixture. The amounts of bromine and chlorine in the mixed salts were determined from these data by the solution of a simple algebraical equation.

Lithium.—The contents of the retort after the distillation of the bromine were united with the residues of the extractions by alcohol, the excess of sulphuric acid was volatilized, the residue dissolved in hydrochloric acid, the sulphates converted to chlorides by means of barium chloride, the baric sulphate thus formed separated by filtration, alumina, silica, and barium carbonate precipitated by ammonium carbonate and separated by filtration, and the solution evaporated to dryness. The residue was gently ignited to remove ammonium chloride, dissolved in water acidulated with hydrochloric acid, and this solution, concentrated until just ready to deposit, was drenched with strong alcohol. The sodium chloride precipitated was washed with alcohol until the spectroscope indicated entire freedom from lithium chloride. The alcoholic solution of lithium chloride was evaporated to dryness, and the residue was dissolved in a little water acidulated with hydrochloric acid. This solution was treated with a little pure barium hydrate (made from the nitrate precipitated from nitric acid) to remove traces of magnesia, and filtered, and from the filtrate the barium was removed by treatment with ammonium carbonate, repeated if necessary. From the solution of lithium chloride thus obtained the lithium was separated according to Mayer's method[2] by evaporation with hydro-disodic phosphate and sodium hydrate, the treatment of the residue with sufficient hot water to dissolve the salts, which should be soluble with the aid of gentle heat, the addition of an equal volume of ammonia, and digestion

[1] Bulletin of the U. S. Geological Survey, No. 42, p. 89; Am. Chem. Jour., vol. 8, p. 421.

[2] *Fresenius's* Quant. Anal., 6th Aufl., Band II. p. 215.

in the cold during twelve hours. The precipitate was filtered upon asbestos in a perforated crucible, washed with a mixture of equal parts of ammonia and water, ignited, and weighed. The filtrate from this precipitate was evaporated, and the residue of evaporation was again treated as before to recover traces of lithium; and a similar process of treatment was applied to the filtrate from the second precipitate. The three precipitates thus obtained contained presumably all the lithium as the tribasic phosphate.

This is the method of determining lithium which was employed previous to the development of the process which has been described in connection with the account of the determination of lithium in the natural waters (p. 22). Were the work to be repeated we should unquestionably employ the amyl alcohol process exclusively, although it may be said for the determinations by Mayer's method that their actual error was very much diminished by the use of comparatively larger portions of material for the analysis, and we are confident that the results are, on that account, fairly trustworthy.

Cæsium, rubidium, and thallium.—The filtrate from lithium phosphate was freed from ammonia by boiling; the phosphoric acid was precipitated by ferric chloride and ammonia, with the usual precautions to secure a suitable proportion of the iron salt and to keep the excess of ammonia at the lowest possible limit, and removed by filtration; the filtrate from ferric phosphate and ferric hydrate was evaporated to dryness and gently ignited to remove ammonium salts; the residue thus left was dissolved in water and treated with platinic chloride in excess of the amount necessary to convert all the alkaline chlorides present to platinum salts.

The precipitate by platinic chloride was extracted by boiling repeatedly with small portions of water, and the residues of this treatment were tested from time to time spectroscopically. The characteristic lines of cæsium and rubidium appeared more distinctly toward the end of the process of extraction when they were visible at all. Thallium, which should appear, if present, in the intermediate extracts, failed to show itself in any of the waters.

Arsenic, antimony, tin, copper, and lead.—The weighed portion of the concentrated solution was acidified with hydrochloric acid, heated to 70° C., and submitted to the action of a current of hydrogen sulphide during several hours. The precipitated sulphide was filtered off upon anthracene in a perforated crucible, following the method described by one of us.[1] The crucible with the adherent filter of anthracene and the precipitate were placed in a small beaker, drenched with benzol, and gently warmed until the anthracene dissolved. Water containing sodium hydrate was added and, after sufficient digestion on the water-bath, the liquid and precipitate were transferred to a paper filter, pre-

[1] Bulletin of the U. S. Geological Survey, No. 42, p. 86; Am. Chem. Jour., vol. 7, 1885–'86, p. 87.

viously moistened with water. In this manner the aqueous solution, carrying the arsenic, antimony, and tin, if present, was permitted to traverse the filter, while the sulphides of copper and lead, with possibly free sulphur, remained with the benzol upon the filter. After thorough washing with water the receptacle for the filtrate was changed, the filter was moistened with alcohol, and thus the benzol, with the anthracene in solution, was induced to pass through the paper, which, with the residue upon it was washed with benzol followed by alcohol and then by water. The filter was carefully incinerated, and the ash was digested with a few drops of nitric acid. The solution thus obtained was evaporated to dryness, the residue was moistened with hydrochloric acid, and, after the volatilization of the most of the acid, dissolved in hot water. From this solution hydrogen sulphide should precipitate copper and lead as sulphides. In the single case of that water which had been concentrated in porcelain no black sulphide was obtained at this point in the operation; in other cases, a trifling black precipitate fell, which subsequent examination proved to be copper sulphide exclusively, doubtless originating in the concentrating vessel.

The second precipitation with hydrogen sulphide was introduced to test the presence of copper and lead, in the process just outlined, because the residue left upon the filter when the benzol is washed from it is apt to be dark in color, even in the absence of black sulphides.

The alkaline filtrate from the benzol and the insoluble residue were acidified with hydrochloric acid, after the addition of a drop or two of ammonium sulphide; the precipitate was filtered off on asbestos in a perforated crucible; the filter and precipitate were dried and treated in a small beaker with fuming nitric acid; the solution in nitric acid was evaporated to dryness, the residue was dissolved in hydrochloric acid, and from this solution, made strongly alkaline with ammonia containing some ammonium sulphide (the last to keep tin, if present, in solution), but kept small in volume, the arsenic was precipitated by the magnesium chloride mixture. The liquid was briskly stirred and then allowed to stand quietly for twelve hours at least. The precipitate was transferred by means of the mother liquor, without the use of other liquid, to a perforated crucible carrying an asbestos felt, washed with a mixture of one part of ammonia to three of water, dried carefully, ignited in an atmosphere of oxygen, and weighed as magnesium pyroarsenate.

The filtrate from the ammonio-magnesium arsenate, which should contain the antimony and tin of the water, was evaporated to remove the great excess of the ammonia, and acidified with hydrochloric acid. The sulphur thus precipitated should carry with it the antimony and tin as sulphides. In no case were we able to detect antimony in this precipitate. In one or two cases there were evidences of the presence *of tin, but this* doubtless came from the lining of the vessel in which

concentration was effected; in the water which was concentrated in porcelain no tin was found.

Boric acid.—The filtrate from the original precipitate by hydrogen sulphide in the acid solution was warmed gently, submitted to the action of a current of air to blow out the excess of hydrogen sulphide, brought nearly to neutrality by the addition of sodium carbonate, made faintly alkaline with ammonia, filtered from the precipitate thus thrown down, and evaporated nearly to dryness after the addition of enough sodium hydrate to expel the ammonia and yet preserve strong alkalinity. The residue was acidified with hydrochloric acid and extracted thoroughly with alcohol, and the alcoholic solution was made alkaline with sodium hydrate and evaporated to dryness. This residue was dissolved in water, just acidified with hydrochloric acid, and from the solution the last traces of silica, alumina, lime, and phosphoric acid were removed by the action of ammonia and ammonium carbonate, and filtration. In the filtrate the boric acid was determined according to Marignac's process, by treatment with magnesium chloride, ammonium chloride, and ammonia, evaporation to dryness, ignition at a red heat, extraction with boiling water, and the repetition upon the extract of the process of evaporation, ignition, and extraction. The residues left after extraction were together ignited and weighed, and the magnesia in the weighed material was determined by precipitation as the ammonio-magnesium phosphate and weighing as the pyrophosphate. The difference between the weight of the residue and its contents in magnesia is boric acid.

This was the process which we employed in the earlier determinations. The process which was developed later, and applied to the determination of boric acid in the natural waters, is preferable.

STATEMENT OF THE RESULTS OF ANALYSIS.

In stating the facts deduced from the analysis of the waters, it has seemed best to adopt the plan of recording the oxygen acids as anhydrides, the basic elements as such, and the oxygen which must exist in combination with the bases by itself; thus avoiding an arbitrary division of the basic elements among the oxygen acids and halogens. The basic oxygen, so called, of the alkaline waters was found by computing the amount of oxygen which would exist in the oxides of the basic elements and deducting from this amount the weight of oxygen equivalent to the halogen discovered by analysis. In the case of waters which carried such an excess of acid that the halogens may be supposed to be uncombined with bases, the basic oxygen is the amount of oxygen which would exist in the oxides of the basic elements. In waters of such acidity that a portion only of the halogen may be supposed to be in combination with basic elements the equivalent in oxygen of the amount of

halogen which is regarded as in combination was deducted from the total amount of oxygen of the oxides in computing the basic oxygen. The halogen which remains uncombined with the basic elements was, as a matter of course, assumed to be in association with hydrogen.

The hypothetical combination of the elements found in the waters must necessarily be largely imaginary, for nothing is more plainly evident than the impossibility of stating authoritatively, in the present condition of knowledge, the actual division of a number of acids among a number of bases in solution. This we do know, that the combination is determined not only by the relative proportions of all the constituents, but by the absolute quantities of all associated in a definite amount of liquid. It is with no purpose, therefore, of attempting to represent actual conditions of combination, but only for the sake of securing a common ground of comparison among themselves and with other waters, that we have assumed arbitrarily the existence in these waters of the definite and simple combinations of the following scheme:

In alkaline waters, bromine has been combined as KBr; B_2O_3 as $Na_2B_4O_7$; As_2O_3 as $NaAsO_2$; P_2O_5 as Na_2HPO_4; chlorine has been assigned to the bases in the order NH_4, Li, K, Na; SO_3 has been linked with such bases as remain in the order NH_4, Li, K, Na, Mg, Ca; residual bases have been classed as neutral carbonates in the order Mg, Ca, Na; residual sodium has been represented as $NaSiO_3$; aluminum and iron have been put down as Al_2O_3 and Fe_2O_3; and residual CO_2 and SiO_2 have been shown as such.

In making up the hypothetical composition of acid waters the same general arrangement has been kept as far as possible in order to secure ready comparison with the alkaline waters. Though the relative avidity of hydrochloric acid is greater at ordinary temperatures than that of sulphuric acid, we have nevertheless represented hydrochloric acid as the free acid whenever it became necessary to represent one of them as free.

The sulphuric acid indicated by the analysis has been combined with the bases in the order Ca, Mg, Al_2, Fe_2, Na, K, Li, NH_4; the residual bases have been combined with chlorine in the same order; the anhydrides B_2O_3, As_2O_3, P_2O_5, SiO_2, CO_2, and residual SO_3, have been stated as such; residual chlorine has been represented as HCl, and H_2S as such.

It is apparent that in some instances combinations have been imagined which might exist under some of the circumstances encountered, but which are improbable under other conditions met with in waters of a generally similar character; thus, for the sake of uniformity, we have represented the boric acid of the alkaline waters invariably as $Na_2B_4O_7$, and the phosphoric acid as Na_2HPO_4, regardless of the variable action of an excess of alkaline carbonate upon these salts in hot solutions and *under prolonged* digestion. So, also SiO_2 has been stated as free, *when, if so, it* must have been in solution in the presence of the carbon-

ates of sodium, magnesium, and calcium; the neutral carbonates have been represented as such in the presence of free carbonic acid, both in hot and in cold waters; and potassium has been arbitrarily associated with bromine; and ammonium, lithium, and potassium have been preferred to other bases in combining the chlorine.

In the following tables are given the direct results of analysis in grams per kilogram of water, and the percentage composition of the material shown by the analysis; the hypothetical combination in grams per kilogram of water, and the percentage composition of the material of the hypothetical combination; the quantity of water used in each determination, and the number of determinations of each constituent. In the final table all the direct results of analysis are summarized.

ANALYSES.

CLEOPATRA SPRING.

(Locality, Mammoth Hot Springs; date of collection, July 23, 1884; temperature, 67° C.; reaction, alkaline; specific gravity, 1.00295.)

Sample No. 1 was taken from the center of the spring.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.0517	2.48	2	200
SO_3	0.4395	21.08	2	200
CO_2	0.6287	30.15	2	200
B_2O_3	0.0226	1.08	2	500
As_2O_3	0.0031	0.15	2	500
Cl	0.1749	8.39	2	200
Br	Trace	.....	1	100
H_2S	Trace	.....	1	600
O (basic)	0.1954	9.37	..	....
Fe } Al }	0.0049	0.23	2	200
Ca	0.3076	14.75	2	200
Mg	0.0729	3.50	2	200
K	0.0511	2.45	2	200
Na	0.1299	6.23	2	200
Li	0.0023	0.11	2	200
NH_4	0.00063	0.03	1	50
	2.08523	100.00		

Albuminoid ammonia (not in summation) 0.00020 grams per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0019	0.09
LiCl	0.0140	0.67
NaCl	0.1903	9.13
KCl	0.0976	4.68
KBr	Trace	.....
Na_2SO_4	0.1448	6.94
$MgSO_4$	0.3645	17.48
$CaSO_4$	0.1953	9.37
$Na_2B_4O_7$	0.0226	1.56
$NaAsO_2$	0.0041	0.20
$CaCO_3$	0.6254	29.99
Al_2O_3	0.0093	0.45
SiO_2	0.0517	2.48
CO_2	0.3537	16.96
H_2S	Trace	.....
	2.0852	100.00

Sample No. 2 was taken at a point in the overflow about 85 feet (25 vertically and 60 horizontally) from the margin of the basin, for the purpose of getting some idea of the rate at which the water near the source was depositing travertine. The sample was collected at the same time with No. 1. The temperature of the water had fallen at the place where the sample was taken to 44° C. The determinations were not duplicated, and a portion of 150 g. was devoted to each determination. The deposit of calcium carbonate, which was found in the sample on cooling and standing—though the water was clear when it was bottled—was analyzed separately.

Constituents.	Grams per kilo of water.		
	In the water.	In the deposit.	Total.
SO_3	0.4573	.....	0.4573
CO_2	0.3433	0.0433	0.3866
Ca	0.1926	0.0578	0.2504
Mg	0.0786	0.0011	0.0797

If it be assumed that at the point at which the sample was taken, the water still carries the sulphates with which it left the source—and this assumption is consonant with the fact that the travertine deposits of these springs carry only trifling amounts of sulphuric acid—the comparison of the analyses of Nos. 1 and 2 indicates that during the flow of the water, hot, thinly spread, and thoroughly churned, 4 per cent. of it was lost by evaporation; and that every kilogram of water which left the source and made this passage deposited something like 0.1675 g. of calcium carbonate.

Sample No. 3 was taken as a preliminary specimen October 11, 1883. The sulphuric acid, carbonic acid, and calcium were alone determined:

	Grams per kilo.
SO_3	0.4254
CO_2	0.5071
Ca	0.3006

It will be noted that the small sample of 1883 carried about the same amount of lime, a little less sulphuric acid, and very much less carbonic acid than the sample of the year following. The deficiency in carbonic acid may have resulted from imperfect sealing of the bottle in which the water was preserved, and the lapse of time before the analysis was made.

ORANGE SPRING.

(Locality, Mammoth Hot Springs; date of collection, October 11, 1883; temperature, 63° C.; reaction, alkaline.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.0502	2.94	1	500
SO_3	0.4407	25.84	1	250
CO_2	0.3378	19.81	1	500
B_2O_3	Present	.....	1	....
As_2O_3	.....	.....	1	....
Cl	0.1623	9.51	1	250
Br	Trace	.....	1	....
H_2S	None *a*	.....	1	....
O (basic)	0.1796	10.53	1	....
Fe, Al	0.0012	0.07	1	500
Ca	0.2821	16.54	1	500
Mg	0.0659	3.86	1	500
K	0.0610	3.58	1	500
Na	0.1233	7.23	1	500
Li *b*	0.0016	0.09	1	500
NH_4	.....	.....	..	....
	1.7057	100.00		

a As received in the laboratory. *b* By Mayer's method.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
LiCl	0.0097	0.57
NaCl	0.1636	9.59
KCl	0.1165	6.83
KBr	Trace	.....
Na_2SO_4	0.1834	10.75
$MgSO_4$	0.3295	19.32
$CaSO_4$	0.2002	11.74
$CaCO_3$	0.5580	32.71
Al_2O_3	0.0022	0.13
SiO_2	0.0502	2.94
CO_2	0.0924	5.42
	1.7057	100 00

HOT RIVER.

(Locality, Mammoth Hot Springs; date of collection, October 5, 1884; temperature, 58° C.; reaction, alkaline; specific gravity, 1.00157.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.0500	2.87	2	200
SO_3	0.4230	24.26	2	200
CO_2	0.4270	24.49	2	200
B_2O_3	0.0128	0.73	2	500
As_2O_3	0.0004	0.02	2	500
Cl	0.1604	9.20	2	100
Br	None	.....	1	100
H_2S	None	.....	1	600
O (basic)	0.1682	9.64	..	....
Fe, Al	0.0051	0.29	2	200
Ca	0.2360	13.53	2	200
Mg	0.0631	3.62	2	200
K	0.0462	2.65	2	100
Na	0.1506	8.63	2	100
Li	0.0011	0.06	2	100
NH_4	0.00011	0.01	1	50
	1.74401	100.00		

Albuminoid ammonia, trace.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0003	0.02
LiCl	0.0068	0.39
NaCl	0.1855	10.64
KCl	0.0882	5.06
Na_2SO_4	0.2205	12.98
$MgSO_4$	0.3155	18.09
$CaSO_4$	0.1450	8.31
$Na_2B_4O_7$	0.0185	1.06
$NaAsO_2$	0.0004	0.02
$CaCO_3$	0.4833	27.71
Al_2O_3	0.0097	0.56
SiO_2	0.0500	2.87
CO_2	0.2143	12.20
	1.7440	100.00

GARDINER RIVER.

(Locality, above Hot River; date of collection, October 12, 1883; temperature, 8° C.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.0469	21.95	2	100
SO_3	0.0117	5.47	2	100
CO_2	0.0710	33.23	2	200
Cl	0.0049	2.29	2	100
O (basic)	0.0216	10.11	..	....
Fe, Al	0.0042	1.96	2	100
Ca	0.0250	11.70	2	100
Mg	0.0005	0.23	2	100
K	0.0079	3.70	2	100
Na	0.0200	9.36	2	100
Li	Trace	.....	..	....
	0.2137	100.00		

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
LiCl	Trace	.....
KCl	0.0103	4.82
K_2SO_4	0.0056	2.62
Na_2SO_4	0.0161	7.53
Na_2CO_3	0.0340	15.91
$MgCO_3$	0.0018	0.84
$CaCO_3$	0.0625	29.25
Al_2O_3	0.0079	3.70
SiO_2	0.0469	21.95
CO_2	0.0286	13.38
	0.2137	100.00

GARDINER RIVER.

(Locality, Mammoth Hot Springs, below Hot River; date of collection, September 26, 1884; temperature, 13° C.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.0272	5 51	2	500
SO_3	0.0802	16.24	2	500
CO_2	0.1725	34.94	2	500
Cl	0.0301	6.10	2	500
O (basic)	0.0487	9.86	..	....
Fe, Al	0.0010	0.20	2	500
Ca	0.0749	15.17	2	500
Mg	0.0175	3.55	2	500
K	0.0105	2.13	2	500
Na	0.0311	6.30	2	500
Li	Trace	.....	..	....
	0.4937	100.00		

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
LiCl	Trace	....
KCl	0.0200	4.05
NaCl	0.0339	6.87
Na_2SO_4	0.0549	11.12
$MgSO_4$	0.0739	14.97
$MgCO_3$	0.0094	1.90
$CaCO_3$	0.1873	37.94
Al_2O_3	0.0019	0.38
SiO_2	0.0272	5.51
CO_2	0.0852	17.26
	0.4937	100.00

WATER SUPPLY AT MAMMOTH HOT SPRINGS.

(Locality, faucet in hotel; date of collection, July 28, 1884.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.0355	12.88	2	1000
SO_3	0.0310	11.24	2	1000
CO_2	0.1230	44.61	2	200
Cl	0.0022	0.80	2	500
O (basic)	0.0248	9.00	..	....
Al, Fe	0.0011	0.40	2	1000
Ca	0.0316	11.46	2	1000
Mg	0.0089	3.23	2	1000
K	0.0031	1.12	2	1000
Na	0.0145	5.26	2	1000
Li	None	.....	..	....
	0.2757	100.00		

Ammonia, 0.000022 gram; albuminoid ammonia, 0.000028 gram; nitric acid, 0.000115 gram per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Grains per U. S. gallon.
KCl	0.0046	1.67	0.2685
K_2SO_4	0.0015	0.54	0.0875
Na_2SO_4	0.0448	16.25	2.6151
$MgSO_4$	0.0076	2.76	0.4436
$MgCO_3$	0.0258	9.36	1.5060
$CaCO_3$	0.0780	28.65	4.6114
Al_2O_3	0.0021	0.76	0.1225
SiO_2	0.0355	12.88	2.0722
CO_2	0.0748	27.13	4.3662
	0.2757	100.00	16.0930

SODA SPRING.

(Locality, Mammoth Hot Springs; date of collection, ——, 1887; temperature, 6° C.; reaction, acid; specific gravity, 1.00041.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.0184	2.08	2	500
SO_3	0.0390	4.42	2	200
CO_2	0.6735	76.30	2	200
B_2O_3	None	.....	2	1,000
As_2O_3	None	.....	2	1,000
Cl	0.0044	0.50	2	200
H_2S	None	.....	..	200
O(basic)	0.0432	4.89	..	.....
Fe	0.0053	0.60	2	500
Al	0.0004	0.06	2	500
Ca	0.0808	9.15	2	500
Mg	0.0106	1.20	2	500
K	0.0027	0.31	2	200
Na	0.0039	0.44	2	200
Li	None	.....	2	200
NH_4	0.0005	.05	2	50
	0.8827	100.00		

Albuminoid ammonia: Trace.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0015	0.17
LiCl	None	.....
KCl	0.0051	0.58
NaCl	0.0015	0.17
Na_2SO_4	0.0102	1.16
$MgSO_4$	0.0500	5.67
$MgCO_3$	0.0021	.24
$CaCO_3$	0.2020	22.88
Fe_2O_3	0.0076	.86
Al_2O_3	0.0008	.09
SiO_2	0.0184	2.08
CO_2	0.5835	66.10
	0.8827	100.00

FEARLESS GEYSER.

(Locality, Norris Geyser Basin; date of collection, August 18, 1884; temperature, 88° C.; reaction, neutral; specific gravity, 1.00110.)

Constituents	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.4180	25.60	2	500
TiO_2	None	.....	1	39,500
SO_3	0.0367	2.25	2	1000
CO_2	0.0046	0.28	2	500
N_2O_5	None	.....	1	400
P_2O_5	None	.....	1	39,500
B_2O_3	0.0223*a*	1.36	2	7,900
As_2O_3	0.0022	0.14	2	7,900
Cl	0.6705	41.06	2	200
Br_2	0.0026	0.16	2	7,900
I	None	.....	2	7,900
Fl	None	.....	1	39,500
H_2S	Trace	.....	1	600
O(basic)	0.0113	0.70	..	.....
Fe	0.0006	0.04	2	39,500
Al	0.0002	0.01	2	500
Mn	None	.....	1	39,500
Ba	None	.....	1	39,500
Sr	None	.....	1	39,500
Ca	0.0092	0.56	2	500
Mg	0.0001	0.01	2	500
Cs	Trace	.....	1	7,900
Rb	Trace	.....	1	7,900
K	0.0415	2.54	2	200
Na	0.4046	24.77	2	200
Li	0.0081*b*	0.50	2	7,900
NH_4	0.00025	0.02	1	500
	1.63275	100.00		

a Found by Marignac's method. *b* Found by Mayer's method.

Albuminoid ammonia (not in summation) 0.00001 grams per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0007	0.04
LiCl	0.0492	3.02
KCl	0.0768	4.71
KBr	0.0039	0.24
CsCl	Trace	.....
RbCl	Trace	.....
NaCl	0.9760	59.78
Na_2SO_4	0.0404	2.47
$MgSO_4$	0.0005	0.03
$CaSO_4$	0.0230	1.41
$Na_2B_4O_7$	0.0319	1.96
$NaAsO_2$	0.0029	0.18
$CaCO_3$	0.0061	0.37
$FeCo_3$	0.0011	0.06
Al_2O_3	0.0004	0.02
SiO_2	0.4180	25.60
Co_2	0.0019	0.11
H_2S	Trace	Trace
	1.6328	100.00

The analysis of a preliminary sample of 1,350 cm³., taken September 27, 1883, yielded the following figures, which signify grams of material per kilogram of water: SiO_2 0.3463; SO_3 0.0501; Cl 0.6476; Fe, Al 0.0021; Ca 0.0098; Mg trace; K 0.0443; Na 0.3931; Li 0.0042.

PEARL GEYSER.

(Locality, Norris Geyser Basin; date of collection, August 20, 1884; temperature, 84° C.; reaction, neutral; specific gravity, 1.00110.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.4636	27.89	2	500
TiO_2	None	.....	1	54,000
SO_3	0.0228	1.38	2	1,000
CO_2	0.0075	0.45	2	200
N_2O_5	.....	.....	1	.....
P_2O_5	None	.....	1	54,000
B_2O_3	[0.0273]	[1.65]	..	.....
As_2O_3	0.0038	0.23	2	3,200
Cl	0.6520	39.22	2	200
Br	.....	.....	..	.....
I	.....	.....	..	.....
Fl	None	.....	1	54,000
H_2S	Trace	.....	1	600
O(basic)	0.0134	0.81	..	.....
Fe	Trace	.....	1	54000
Al	0.0031	0.18	2	500
Mn	Trace *a*	.....	1	54,000
Ba	None	.....	1	54,000
Sr	None	.....	1	54,000
Ca	0.0064	0.38	2	500
Mg	0.0009	0.05	2	500
Cs	.....	.....	..	.....
Rb	.....	.....	..	.....
K	0.0544	3.27	2	200
Na	0.4046	24.34	2	200
Li	0.0022 *b*	0.14	2	10,800
NH_4	0.00021	0.01	1	1,000
	[1.66221]	[100.00]		

a 0.000038 gram. *b* By Mayer's method.

Albuminoid ammonia (not included in summation) 0.00001 g.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0006	0.03
LiCl	0.0133	0.80
KCl	0.1039	6.26
NaCl	0.9738	58.59
Na_2SO_4	0.0366	2.21
$CaSO_4$	0.0037	0.22
$NaAsO_2$	0.0050	0.30
$Na_2B_4O_7$	[0.0394]	[2.37]
$MgCO_3$	0.0031	0.18
$CaCO_3$	0.0133	0.80
Al_2O_3	0.0059	0.35
SiO_2	0.4636	27.89
H_2S	Trace	.....
	[1.6622]	[100.00]

An accidental loss of the material for analysis prevented the determinations of the boric acid, bromine, iodine, calcium, and rubidium. In the figures given above it has been assumed, in order that the analysis may be utilized as far as may be for comparison with the others, that the boric acid was present in amount just sufficient to neutralize the excess of base over all acid in the dissolved material. This supposition is probably not very far wrong, if we may draw any conclusion in this matter from the composition of adjacent waters, but it is nevertheless purely an assumption.

CONSTANT GEYSER.

(Locality, Norris Basin; date of collection, September 13, 1885; temperature, 92° C.; reaction, acid; specific gravity, 1.00115.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.4685	28.88	2	200
SO_3	0.0923	5.69	2	200
CO_2	0.0155	0.95	2	200
B_2O_3	0.0317	1.95	2	500
As_2O_3	0.0018	0.11	2	500
Cl	0.5740	35.39	2	200
Br	Trace	.....	2	100
H_2S	None *a*	....	1	600
O(basic)	0.0185	1.14	..	....
Fe	Trace	.....	2	200
Al	0.0048	0.29	2	200
Ca	0.0146	0.90	2	200
Mg	0.0018	0.11	2	200
K	0.0745	4.60	2	200
Na	0.3190	19.67	2	200
Li	0.0030	0.19	2	200
NH_4	0.00127	0.08	1	50
H (in HCl)	0.0008	.05	..	....
	1.62207	100.00		

a As received in the laboratory.

Albuminoid ammonia, none.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0038	0.23
LiCl	0.0182	1.14
KCl	0.1423	8.77
KBr	Trace	.....
NaCl	0.7590	46.79
Na_2SO_4	0.0635	3.91
$MgSO_4$	0.0090	0.55
$CaSO_4$	0.0496	3.07
$Al_2(SO_4)_3$	0.0304	1.88
$Fe_2(SO_4)_3$	Trace	.....
SiO_2	0.4685	28.88
B_2O_3	0.0317	1.95
As_2O_3	0.0018	0.11
CO_2	0.0155	0.95
HCl	0.0287	1.77
	1.6220	100.00

CORAL SPRING.

(Locality, Norris Geyser Basin; date of collection, August 20, 1884; temperature, 73° C.; reaction, acid; specific gravity, 1.00130.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.6070	31.77	2	200
SO_3	0.0264	1.38	2	200
CO_2	0.0425	2.22	2	200
B_2O_3	0.0328	1.71	2	1,000
As_2O_3	0.0007	0.04	2	1,000
Cl	0.7087	37.09	2	100
H_2S	None	.....	1	600
O (basic)	0.0053	0.28	..	.....
Fe	Trace	.....	..	200
Al	0.0029	0.15	2	200
Ca	0.0102	0.54	2	200
Mg	0.0022	0.11	2	200
K	0.0729	3.81	2	100
Na	0.3936	20.60	2	100
Li	0.0020	0.11	2	100
NH_4	0.00042	0.02	1	50
H (in HCl)	0.0032	0.17		.....
	1.91082	100.00		

Albuminoid ammonia (not in summation), 0.00010 grams per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0012	0.06
LiCl	0.0121	0.64
KCl	0.1393	7.29
NaCl	1.0011	52.39
$MgCl_2$	0.0016	0.08
Al_2Cl_6	0.0143	0.75
Fe_2Cl_6	Trace	.....
$MgSO_4$	0.0090	0.46
$CaSO_4$	0.0347	1.82
B_2O_3	0.0328	1.72
As_2O_3	0.0007	0.04
SiO_2	0.6070	31.77
CO_2	0.0425	2.22
HCl	0.0145	0.76
	1.9108	100.00

CORAL SPRING.

(Locality, Norris Geyser Basin; date of collection, October 11, 1886; temperature, 72° C.; reaction, faintly acid; specific gravity, 1.00124.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.5805	31.30	2	200
SO_3	0.0280	1.51	2	200
CO_2	0.0262	1.41	2	200
B_2O_3	0.0368	1.98	2	500
As_2O_3	0.0009	0.05	2	500
Cl	0.6701	36.14	2	200
H_2S	None	.....	1	600
O(basic)	0.0175	0.94	..	....
Fe	Trace	.....	2	200
Al	0.0077	0.42	2	200
Ca	0.0071	0.39	2	200
Mg	0.0014	0.07	2	200
K	0.0815	4.40	2	200
Na	0.3925	21.16	2	200
Li	0.0040	0.21	2	200
NH_4	0.0003	0.02	1	50
	1.8545	100.00		

Albuminoid ammonia (not in summation) 0.00060 gram per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0009	0.05
LiCl	0.0243	1.31
KCl	0.1557	8.39
NaCl	0.9483	51.13
Na_2SO_4	0.0228	1.23
$MgSO_4$	0.0070	0.39
$CaSO_4$	0.0179	0.96
$Na_2B_4O_7$	0.0531	2.86
$NaAsO_2$	0.0012	0.07
$CaCO_3$	0.0048	0.26
Al_2O_3	0.0139	0.75
Fe_2O_3	Trace	.....
SiO_2	0.5805	31.30
CO_2	0.0241	1.30
	1.8545	100.00

ECHINUS SPRING.

(Locality, Norris Geyser Basin; date of collection, August 20, 1884; temperature, 91° C.; reaction, acid; specific gravity, 1.00071.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.2532	30.46	2	200
SO_3	0.1929	23.21	2	200
CO_2	0.0250	3.01	2	200
B_2O_3	0.0173	2.08	2	500
As_2O_3	0.0016	0.19	2	500
Cl	0.1207	14.52	2	200
Br	Trace	.....	2	100
H_2S	Trace	.....	1	600
O(basic)	0.0386	4.64	..	....
Fe	None	.....	2	200
Al	0.0027	0.33	2	200
Ca	0.0115	1.38	2	200
Mg	None	.....	2	200
K	0.0395	4.75	2	200
Na	0.1265	15.22	2	200
Li	Trace	.....	2	200
NH_4	0.00106	0.13	1	50
H(in HCl)	0.0007	0.08	..	....
	0.83126	100.00		

Albuminoid ammonia: None.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0040	0.48
LiCl	Trace	.....
KCl	0.0754	9.07
KBr	Trace	.....
NaCl	0.0908	10.92
Na_2SO_3	0.2803	33.72
$CaSO_4$	0.0391	4.70
$Al_2(SO_3)_4$	0.0171	2.06
SiO_2	0.2532	30.46
B_2O_3	0.0173	2.08
As_2O_3	0.0016	0.19
CO_2	0.0250	3.01
HCl	0.0275	3.31
H_2S	Trace	.....
	0.8313	100.00

SCHLAMMKESSEL.

(Locality, Norris Geyser Basin; date of collection, August 20, 1884; temperature, 91° C.; reaction, acid; specific gravity, 1.00130.)

The water was filtered from material in suspension.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.4577	27.04	2	200
SO_3	0.1012	5.98	2	100
CO_2	0.0175	1.04	2	100
B_2O_3	0.0390	2.30	2	200
AS_2O_3	None	.....	1	200
Cl	0.6391	37.75	2	100
Br	Trace	.....	1	100
H_2S	Trace *a*	.....	..	....
O (basic)	0.0202	1.19	..	....
Fe, Al	0.0081	0.48	2	200
Ca	0.0078	0.46	2	200
Mg	0.0003	0.02	2	200
K	0.0254	1.50	2	200
Na	0.3654	21.58	2	200
Li	0.0029	0.17	2	200
NH_4	0.00633	0.37	1	50
H (in HCl)	0.0019	0.12	..	....
	1.69283	100.00		

a As received in the laboratory.

Albuminoid ammonia (not in summation) 0.00040 grams per kilo.

Hypothetical Combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0188	1.11
LiCl	0.0176	1.03
KCl	0.0485	2.86
KBr	Trace	.....
NaCl	0.8585	50.72
Na_2SO_4	0.0862	5.09
$MgSO_4$	0.0015	0.09
$CaSO_4$	0.0265	1.57
$Al_2(SO_4)_3$, $Fe_2(SO_4)_3$	0.0513	3.03
SiO_2	0.4577	27.04
B_2O_3	0.0390	2.30
CO_2	0.0175	1.04
HCl	0.0697	4.12
H_2S	Trace	.....
	1.6928	100.00

FOUNTAIN GEYSER.

(Locality, Lower Geyser Basin; date of collection, August 24, 1884; temperature, 82° C.; reaction, alkaline; specific gravity, 1.00100.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water in each determination.
SiO_2	0.3315	23.69	2	200
TiO_2	None	.....	1	31,000
SO_3	0.0195	1.39	2	200
CO_2	0.2307	16.48	2	200
N_2O_5	None	.....	1	500
P_2O_5	0.00004	.....	1	31,000
B_2O_3	0.0138*a*	0.99	2	6,200
As_2O_3	0.0027	0.19	2	6,200
Cl	0.3337	23.84	2	100
Br	0.0004	0.03	2	6,200
I	None	.....	2	6,200
Fl	None	.....	1	31,000
H_2S	Trace	.....	1	600
O (basic)	0.0654	4.67	..	.....
Fe	0.0002	0.01	2	31,000
Al	0.0057	0.41	2	200
Mn	Trace *b*	.....	1	31,000
Ba	None	.....	1	31,000
Sr	None	.....	1	31,000
Ca	0.0014	0.10	2	200
Mg	0.0010	0.07	2	200
Cs	None	.....	2	6,200
Rb	None	.....	2	6,200
K	0.0379	2.71	2	100
Na	0.3522	25.16	2	100
Li *c*	0.0035	0.25	2	6,200
NH_4	0.00015	0.01	1	500
	1.39979	100.00		

a By Marignac's method. *b* 0.000003 grams. *c* By Mayer's method.

Albuminoid ammonia (not in summation) 0.00033 grams per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0004	0.02
LiCl	0.0213	1.52
KCl	0.0720	5.15
KBr	0.0006	0.04
NaCl	0.4636	33.12
Na_2SO_4	0.0346	2.47
$Na_2B_4O_7$	0.0198	1.42
$NaAsO_2$	0.0035	0.25
Na_2CO_3	0.3541	25.30
$MgCO_3$	0.0035	0.25
$CaCO_3$	0.0035	0.25
$FeCO_3$	0.0004	0.02
$MnCO_3$	Trace	.....
Al_2O_3	0.0108	0.77
SiO_2	0.3315	23.69
CO_2	0.0801	5.73
H_2S	Trace	.....
	1.3997	100.00

GREAT FOUNTAIN GEYSER.

(Locality, Lower Geyser Basin; date of collection, August 24, 1884; temperature, 82°–93° C.(*a*); reaction, alkaline; specific gravity, 1.00104.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.3182	24.19	2	200
SO_3	0.0187	1.42	2	100
CO_2	0.2107	16.02	2	200
B_2O_3	0.0100*b*	0.76	1	50
As_2O_3	0.0017	0.13	2	500
Cl	0.3508	26.67	2	100
H_2S	None	.....	1	600
O (basic)	0.0472	3.59	..	....
Fe	Trace	.....	2	200
Al	0.0021	0.16	2	200
Ca	0.0017	0.13	2	200
Mg	0.0023	0.17	2	200
K	0.0145	1.10	2	100
Na	0.3351	25.47	2	100
Li	0.0025	0.19	2	100
	1.3155	100.00		

a The usual range of temperature during the interval between eruptions.

b Rests on one determination, and that made with an insufficient amount of water, the remainder having been lost accidentally.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Percent. of total material in solution.
LiCl	0.0152	1.15
KCl	0.0277	2.11
NaCl	0.5354	40.70
Na_2SO_4	0.0332	2.52
$Na_2B_4O_7$	0.0144	1.09
$NaAsO_2$	0.0022	0.17
Na_2CO_3	0.2536	19.28
$MgCO_3$	0.0080	0.61
$CaCO_3$	0.0043	0.33
Al_2O_3	0.0040	0.30
Fe_2O_3	Trace	.....
SiO_2	0.3182	24.19
CO_2	0.0993	7.55
	1.3155	100.00

HYGEIA SPRING.

(Locality, Lower Geyser Basin; date of collection, September 11, 1885; temperature, 43° C.; reaction, alkaline; specific gravity, 1.00107.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.2477	20.98	2	200
SO_3	0.0196	1.65	2	200
CO_2	0.2907	24.62	2	200
B_2O_3	0.0239	2.02	2	500
As_2O_3	0.0034	0.29	2	500
Cl	0.2487	21.06	2	200
Br	Trace	.....	1	100
H_2S	None *a*	.....	..	....
O (basic)	0.0504	4.27	..	....
Fe	None	.....	2	200
Al	0.0036	0.31	2	200
Ca	0.0064	0.54	2	200
Mg	0.0022	0.19	2	200
K	0.0154	1.30	2	200
Na	0.2654	22.48	2	200
Li	0.0032	0.27	2	200
NH_4	0.00021	0.02	1	50
	1.18081	100.00		

a As received in the laboratory.

Albuminoid ammonia, none.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Percent. of total material in solution.
NH_4Cl	0.0006	0.06
LiCl	0.0194	1.64
KCl	0.3594	30.44
KBr	Trace	.....
NaCl	0.0294	2.49
Na_2SO_4	0.0348	2.95
$Na_2B_4O_7$	0.0345	2.92
$NaAsO_2$	0.0049	0.41
Na_2CO_3	0.2393	20.26
$MgCO_3$	0.0077	0.65
$CaCO_3$	0.0160	1.35
Al_2O_3	0.0068	0.58
SiO_2	0.2477	20.98
CO_2	0.1803	15.27
	1.1808	100.00

MADISON SPRING.

(Locality, Terrace Springs, near junction of Gibbon and Firehole Rivers; date of collection, September 11, 1885; temperature, 60° C.; reaction, alkaline; specific gravity, 1.00100.)

Constituents.	Grams per kilo of water.	Percent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.1507	11.37	2	200
SO_3	0.0123	0.93	2	200
CO_2	0.6140	46.31	2	200
B_2O_3	0.0130	0.98	1	500
As_2O_3	Trace	.....	1	500
Cl	0.0698	5.26	2	200
Br	None	.....	1	100
H_2S	None *a*	.....	..	....
O (basic)	0.1062	8.01	..	....
Fe	None	.....	2	200
Al	None *a*	.....	2	200
Ca	0.0255	1.92	2	200
Mg	0.0017	0.13	2	200
K	0.0385	2.90	2	200
Na	0.2930	22.10	2	200
Li	0.0004	0.03	2	200
NH_4	0.0008	0.06	1	50
	1.3259	100.00		

a As received in the laboratory.

Albuminoid ammonia (not in summation), 0.00020 grams per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0024	0.18
LiCl	0.0024	0.18
KCl	0.0735	5.54
NaCl	0.0513	3.87
Na_2SO_4	0.0218	1.65
$Na_2B_4O_7$	0.0187	1.41
$NaAsO_2$	Trace	.....
Na_2CO_3	0.6025	45.44
$MgCO_3$	0.0060	0.45
$CaCO_3$	0.0638	4.81
SiO_2	0.1507	11.37
CO_2	0.3328	25.10
	1.3259	100.00

FIREHOLE RIVER.

(Locality, above the junction of Nez Percé Creek; date of collection, August 24, 1884; temperature, 8° C.; reaction, alkaline; specific gravity, 1.00031.)

The water was filtered before bottling.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determination.	Grams of water employed in each determination.
SiO_2	0.0965	22.10	2	200
SO_3	0.0084	1.92	2	100
CO_2	0.1040	23.83	2	200
B_2O_3	0.0060	1.37	1	340
As_2O_3	None	.....	1	500
Cl	0.0737	16.89	2	100
H_2S	None	.....	..	....
O (basic)	0.0265	6.07	..	....
Fe	Trace	.....	2	200
Al	0.0031	0.71	2	200
Ca	0.0066	1.51	2	200
Mg	0.0007	0.16	2	200
K	0.0170	3.89	2	100
Na	0.0930	21.30	2	100
Li	0.0011	0.25	2	100
	0.4366	100.00		

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
LiCl	0.0067	1.53
KCl	0.0325	7.44
NaCl	0.0867	19.86
Na_2SO_4	0.0149	3.42
$Na_2B_4O_7$	0.0087	1.99
Na_2CO_3	0.1201	27.51
$MgCO_3$	0.0024	0.55
$CaCO_3$	0.0165	3.78
Al_2O_3	0.0059	1.35
Fe_2O_3	Trace	.....
SiO_2	0.0965	22.10
CO_2	0.0457	10.47
	0.4366	100.00

EXCELSIOR GEYSER.

(Locality, Midway Basin; date of collection, August 25, 1884; temperature, 92° C.; reaction, alkaline; specific gravity, 1.00110.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determination.	Grams of water employed in each determination.
SiO_2	0.2214	15.04	2	200
TiO_2	None	.....	1	24,000
SO_3	0.0146	0.99	2	200
CO_2	0.3825	25.97	2	200
N_2O_5	None	.....	2	120
P_2O_5	Trace	.....	1	24,000
B_2O_3	0.0161 *a*	1.09	2	2,400
As_2O_3	0.0026	0.18	2	2,400
Cl	0.2793	18.96	2	100
Br	Trace	.....	2	2,400
I	None	.....	2	2,400
Fl	None	.....	1	24,000
H_2S	Trace	.....	1	600
O (basic)	0.0955	6.49	..	.....
Fe	0.0018	0.12	2	24,000
Al	0.0012	0.08	2	200
Mn	Trace	.....	1	24,000
Ba	None	.....	1	24,000
Sr	None	.....	1	24,000
Ca	0.0022	0.15	2	200
Mg	0.0022	0.15	2	200
Cs	None	.....	2	2,400
Rb	None	.....	2	2,400
K	0.0325	2.21	2	100
Na	0.4186	28.43	2	100
Li	0.0020 *b*	0.14	2	2,400
NH_4	0.00001	.....	1	50
	1.47251	100.00		

a By Marignac's method. *b* By Mayer's method.

Albuminoid ammonia (not in summation), 0.00002 gram per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	Trace	Trace
LiCl	0.0121	0.82
KCl	0.0621	4.22
KBr	Trace	Trace
NaCl	0.3948	26.81
Na_2SO_4	0.0259	1.76
$Na_2B_4O_7$	0.0232	1.58
$NaAsO_2$	0.0034	0.23
Na_2HPO_4	Trace	.....
Na_2CO_3	0.5739	38.97
$MgCO_3$	0.0077	0.52
$CaCO_3$	0.0055	0.37
$FeCO_3$	0.0037	0.25
Al_2O_3	0.0023	0.15
SiO_2	0.2214	15.04
CO_2	0.1365	9.28
H_2S	Trace	Trace
	1.4725	100.00

A preliminary sample of 600 cm³., taken August 29, 1883, yielded as analysis the following figures, which signify grams of material per kilogram of water: SiO_2, 0.2727; SO_3, 0.0107; B_2O_3, present; Cl, 0.2765; Fe and Al, 0.0009; Ca, 0.0055; Li, present.

OLD FAITHFUL GEYSER.

(Locality, Upper Geyser Basin; date of collection, September 1, 1884; temperature, 84°–88° C. (*a*); reaction, alkaline; specific gravity, 1.00096.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.3828	27.52	2	500
TiO_2	None	.....	1	84,000
SO_3	0.0152	1.09	2	1,000
CO_2	0.0894	6.43	2	200
N_2O_5	None	.....	2	1,500
P_2O_5	None	.....	1	84,000
B_2O_3	0.0148*b*	1.07	2	13,500
As_2O_3	0.0021	0.15	2	13,500
Cl	0.4391	31.57	2	200
Br	0.0034	0.25	2	13,500
I	None	.....	2	13,500
Fl	None	.....	1	84,000
H_2S	0.0002	0.01	1	600
O (basic)	0.0419	3.02	.	.....
Fe	Trace	.....	2	84,000
Al	0.0009	0.06	2	500
Mn	Trace*c*	.....	1	84,000
Ba	None	.....	1	84,000
Sr	None	.....	1	84,000
Ca	0.0015	0.11	2	500
Mg	0.0006	0.04	2	500
Cs	Trace	.....	2	27,000
Rb	Trace	.....	2	27,000
K	0.0267	1.92	2	200
Na	0.3666	26.36	2	200
Li	0.0056*d*	.40	2	13,500
NH_4	0.00001	.....	1	50
	1.39081	100.00		

a The usual range of temperature in the pools about the crater, from which the sample was taken immediately after eruption.

b By Marignac's method.

c 0.000005 grams.

d By Mayer's method.

Albuminoid ammonia (not in summation), 0.00002 grams per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl.....	Trace	Trace
LiCl.....	0.0340	2.44
KCl.....	0.6393	45.97
KBr	0.0478	3.44
CsCl.....	Trace	.....
RbCl	Trace	.....
NaCl.....	0.0051	0.37
Na_2SO_4.....	0.0270	1.94
$N_2aB_4O_7$	0.0213	1.53
$NaAsO_2$.....	0.0027	0.19
Na_2CO_3	0.2088	15.02
Na_2SiO_3.....	0.0279	2.01
$MgCO_3$.....	0.0021	0.15
$CaCO_3$	0.0038	0.27
$FeCO_3$	Trace	.....
$MnCO_3$	Trace	.....
Al_2O_3	0.0017	0.12
SiO_2	0.3691	26.54
H_2S.....	0.0002	0.01
	1.3908	100.00

SPLENDID GEYSER.

(Locality, Upper Geyser Basin; date of collection, September 10, 1885; temperature, 93° C.; reaction, alkaline; specific gravity, 1.00132.)

The concentration of the water was effected in porcelain.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.2964	18.14	2	500
TiO_2	None	.....	1	22,000
SO_3	0.0158	0.97	2	500
CO_2	0.4225	25.86	2	200
N_2O_5	None	.....	2	400
P_2O_5	0.00012	0.01	1	22,000
B_2O_3	0.0234	1.43	2	500
As_2O_3	0.0019	0.12	2	4,500
Cl	0.3227	19.75	2	200
Br	None	.....	2	4,500
I	None	.....	2	4,500
Fl	None	.....	1	22,000
H_2S	None	.....	1	600
O (basic)	0.0897	5.49	.	.....
Fe	0.00008	0.005	2	22,000
Al	0.0027	0.16	2	500
Mn	None	.....	1	22,000
Ba	None	.....	1	22,000
Sr	None	.....	1	22,000
Ca	0.0030	0.18	2	500
Mg	0.0005	0.03	2	500
Cs	None	.....	2	9,000
Rb	None	.....	2	9,000
K	0.0121	0.74	2	200
Na	0.4407	26.97	2	200
Li	0.0023	0.14	2	200
NH_4	0.00008	0.005	1	50
	1.63398	100.000		

Albuminoid ammonia (not in summation), 0.00002 grams per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0002	0.01
$LiCl$	0.0140	0.86
KCl	0.0231	1.41
$NaCl$	0.4940	30.23
Na_2SO_4	0.0281	1.72
$Na_2B_4O_7$	0.0335	2.05
$NaAsO_2$	0.0025	0.15
Na_2HPO_4	0.0002	0.01
Na_2CO_3	0.5286	32.36
$MgCO_3$	0.0018	0.11
$CaCO_3$	0.0075	0.46
$FeCO_3$	0.0001	0.01
Al_2O_3	0.0051	0.31
SiO_2	0.2964	18.14
CO_2	0.1989	12.17
	1.6340	100.00

SPLENDID GEYSER.

(Locality, Upper Geyser Basin; date of collection, August 28, 1884; temperature, 93° C.; reaction, alkaline; specific gravity, 1.00127.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.3000	18.81	2	200
SO_3	0.0158	0.99	2	100
CO_2	0.4042	25.34	2	200
B_2O_3	0.0240	1.51	2	500
As_2O_3	0.0010	0.06	2	500
Cl	0.3181	19.94	2	100
Br	None	.....	2	100
H_2S	None	.....	1	600
O (basic)	0.0866	5.43	..	....
Fe	Trace	.....	2	200
Al	0.0034	0.21	2	200
Ca	0.0034	0.21	2	200
Mg	0.0015	0.09	2	200
K	0.0152	0.95	2	100
Na	0.4179	26.20	2	100
Li	0.0037	0.23	2	100
NH_4	0.00042	0.03	2	50
	1.59522	100.00		

Albuminoid ammonia (not in summation) 0.00020 grams per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0012	0.08
LiCl	0.0225	1.41
KCl	0.0290	1.82
NaCl	0.4692	29.41
Na_2SO_4	0.0280	1.76
$Na_2B_4O_7$	0.0346	2.17
$NaAsO_2$	0.0016	0.10
Na_2CO_3	0.4977	31.20
$MgCO_3$	0.0053	0.32
$CaCO_3$	0.0085	0.53
Al_2O_4	0.0064	0.40
SiO_2	0.3000	18.81
CO_2	0.1912	11.99
	1.5952	100.00

GIANTESS GEYSER.

(Locality, Upper Geyser Basin; date of collection, August 29, 1884; temperature, 93° C.; reaction, alkaline; specific gravity, 1.00100.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.3917	27.62	2	200
SO_3	0.0167	1.18	2	200
CO_2	0.1055	7.44	2	200
B_2O_3	0.0233	1.64	2	200
As_2O_3	0.0006	0.04	2	200
Cl	0.4408	31.08	2	100
Br	Trace	.....	2	100
H_2S	Trace	.....	1	600
O (basic)	0.0411	2,90	..	...
Fe	Trace	.....	2	200
Al	0.0049	0.34	2	200
Ca	0.0007	0.05	2	200
Mg	0.0012	0.08	2	200
K	0.0410	2.90	2	100
Na	0.3451	24.33	2	100
Li	0.0057	0.40	2	100
NH_4	.....	.....	..	....
	1.4183	100.00		

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
LiCl	0.0346	2.44
KCl	0.0783	5.52
KBr	Trace	.....
NaCl	0.6173	43.52
Na_2SO_4	0.0296	2.09
$Na_2B_4O_7$	0.0336	2.37
$NaAsO_2$	0.0008	0.06
Na_2CO_3	0.1959	13.81
$MgCO_3$	0.0042	0.30
$CaCO_3$	0.0017	0.12
Al_2O_3	0.0093	0.65
SiO_2	0.3917	27.62
CO_2	0.0213	1.50
H_2S	Trace	.....
	1.4183	100.00

The analysis of a preliminary sample of 1,300 cm^3., taken August 28, 1883, yield the following results, which are given in grams of material per kilogram of water: SiO_2, 0.3843; SO_3, 0.0144; Cl, 0.4384; Fe and Al, 0.0030; Ca, 0.0058; Mg, 0.0002; Li, 0.0043; Na and K, weighed together as chlorides, 0.9559. The chlorides of the sodium and potassium found in the preceding analysis amount to 0.9564 gram.

BEEHIVE GEYSER.

(Locality, Upper Geyser Basin; date of collection, September 1, 1884; temperature, 93° C.; reaction, alkaline; specific gravity, 1.00095.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.3042	25.12	2	200
SO_3	0.0271	2.24	2	100
CO_2	0.0920	7.60	2	200
B_2O_3	0.0145	1.20	2	500
As_2O_3	0.0011	0.09	2	500
Cl	0.3894	32.15	2	100
Br	Trace	.....	2	100
H_2S	None	.....	1	600
O (basic)	0.0364	3.00	..	....
Fe	Trace	.....	2	200
Al	0.0029	0.24	2	200
Ca	0.0039	0.32	2	200
Mg	0.0002	0.02	2	200
K	0.0213	1.76	2	100
Na	0.3118	25.74	2	100
Li	0.0061	0.50	2	100
NH_4	0.00021	0.02	1	50
	1.21111	100.00		

Albuminoid ammonia, none.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0006	0.05
LiCl	0.0370	3.05
KCl	0.0407	3.36
KBr	Trace	.....
NaCl	0.5582	46.09
Na_2SO_4	0.0481	3.97
$Na_2B_4O_7$	0.0209	1.73
$NaAsO_2$	0.0014	0.12
Na_2CO_3	0.1754	14.48
$MgCO_3$	0.0007	0.06
$CaCO_3$	0.0098	0.81
Al_2O_3	0.0055	0.45
SiO_2	0.3042	25.12
CO_2	0.0086	0.71
	1.2111	100.00

GROTTO GEYSER.

(Locality, Upper Geyser Basin; date of collection, August 28, 1884; temperature, 93° C.; reaction, alkaline; specific gravity, 1.00120.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.2590	18.15	2	200
SO_3	0.0148	1.04	2	100
CO_2	0.3155	22.11	2	200
B_2O_3	0.0290	2.03	2	500
As_2O_3	0.0003	0.02	2	500
Cl	0.3045	21.34	2	100
Br	Trace	.....	2	100
H_2S	None	.....	1	600
O (basic)	0.0807	5.66	..	....
Fe	Trace	.....	2	200
Al	0.0036	0.25	2	200
Ca	0.0039	0.28	2	200
Mg	0.0010	0.07	2	200
K	0.0249	1.74	2	100
Na	0.3853	27.00	2	100
Li	0.0041	0.29	2	100
NH_4	0.00023	0.02	1	50
	1.42683	100.00		

Albuminoid ammonia (not in summation) 0.00010 gram per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent of total material in solution.
NH_4Cl	0.0007	0.05
LiCl	0.0249	1.75
KCl	0.0476	3.34
KBr	Trace	.....
NaCl	0.4293	30.09
Na_2SO_4	0.0263	1.84
$Na_2B_4O_7$	0.0418	2.93
$NaAsO_2$	0.0004	0.03
Na_2CO_3	0.4573	32.05
$MgCO_3$	0.0035	0.25
$CaCO_3$	0.0097	0.68
Al_2O_3	0.0068	0.47
SiO_2	0.2590	18.15
CO_2	0.1195	8.37
	1.4268	100.00

TURBAN AND GRAND GEYSERS.

(Locality, Upper Geyser Basin; date of collection, September 1, 1884; temperature, 91° C.; reaction, alkaline; specific gravity, 1.00108.)

The vents of these geysers connect with one another.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.3035	21.83	2	200
SO_3	0.0218	1.57	2	100
CO_2	0.1950	14.02	2	200
B_2O_3	0.0243	1.75	2	500
As_2O_3	0.0011	0.07	2	500
Cl	0.3767	27.09	2	100
Br	Trace	.....	2	100
H_2S	Trace	.....	1	600
O(basic)	0.0596	4.28	..	....
Fe	Trace	.....	2	200
Al	0.0032	0.25	2	200
Ca	0.0028	0.20	2	200
Mg	None	.....	2	200
K	0.0167	1.20	2	100
Na	0.3818	27.46	2	100
Li	0.0036	0.25	2	100
NH_4	0.00042	0.03	1	50
	1.39052	100.00		

Albuminoid ammonia (not in summation) 0.00020 gram per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0012	0.08
LiCl	0.0218	1.57
KCl	0.0319	2.29
KBr	Trace	.....
NaCl	0.5643	40.59
Na_2SO_4	0.0387	2.79
$Na_2B_4O_7$	0.0350	2.52
$NaAsO_2$	0.0014	0.10
Na_2CO_3	0.3209	23.08
$MgCO_3$	None	.....
$CaCO_3$	0.0070	0.50
Al_2O_3	0.0061	0.43
SiO_2	0.3035	21.83
CO_2	0.0587	4.22
H_2S	Trace	.....
	1.3905	100.00

ARTEMISIA GEYSER.

(Locality, Upper Geyser Basin; date of collection, September 1, 1884; temperature, 89° C.; reaction, alkaline; specific gravity, 1.00121.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.2737	18.39	2	200
SO_3	0.0127	0.85	2	100
CO_2	0.3607	24.24	2	200
B_2O_3	0.0177	1.19	2	500
As_2O_3	0.0014	0.09	2	500
Cl	0.2996	20.13	2	100
Br	Trace	.....	2	100
H_2S	None	.....	1	600
O(basic)	0.0903	6.06	..	....
Fe	Trace	.....	2	200
Al	0.0079	0.59	2	200
Ca	0.0014	0.09	2	200
Mg	None	.....	2	200
K	0.0163	1.09	2	100
Na	0.3988	26.80	2	100
Li	0.0070	0.47	2	100
NH_4	0.00021	0.01	1	50
	1.48771	100.00		

Albuminoid ammonia, trace.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0006	0.04
LiCl	0.0425	2.86
KCl	0.0311	2.09
KBr	Trace	.....
NaCl	0.4101	27.56
Na_2SO_4	0.0226	1.52
$Na_2B_4O_7$	0.0202	1.36
$NaAsO_2$	0.0018	0.12
Na_2CO_3	0.5245	35.26
$MgCO_3$	None	none.
$CaCO_3$	0.0035	0.23
Al_2O_3	0.0150	1.01
SiO_2	0.2737	18.40
CO_2	0.1421	9.55
	1.4877	100.00

TAURUS GEYSER.

(Locality, Shoshone Basin; date of collection, July 20, 1887; temperature, 92° C.; reaction, alkaline; specific gravity, 1.00105.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.2926	22.69	2	500
SO_3	0.0385	2.98	2	200
CO_2	0.3210	24.89	2	200
B_2O_3	0.0149	1.16	2	1,000
As_2O_3	0.0007	0.05	2	1,000
Cl	0.1935	15.00	2	200
Br	None	.....	2	100
H_2S	None	.....	..	.....
O (basic)	0.0781	6.05	..	.....
Fe	Trace	.....	2	500
Al	0.0040	0.31	2	500
Ca	Trace	.....	2	500
Mg	0.0009	0.07	2	500
K	0.0235	1.82	2	200
Na	0.3202	24.83	2	200
Li	0.0009	0.07	2	200
NH_4	0.0010	0.08	2	50
	1.2898	100.00		

Albuminoid ammonia, 0.0002 grams per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0030	.24
LiCl	0.0055	.43
KCl	0.0449	3.48
NaCl	0.2729	21.15
Na_2SO_4	0.0630	4.88
$MgSO_4$	0.0045	.35
$Na_2B_4O_7$	0.0215	1.67
$NaAsO_2$	0.0009	.07
Na_2SiO_3	0.4971	38.54
SiO_2	0.0480	3.72
CO_2	0.3210	24.89
Al_2O_3	0.0075	.58
Fe_2O_3	Trace	Trace
	1.2898	100.00

ASTA SPRING.

(Locality, Hillside Springs; date of collection, September 16, 1884; temperature, 84°C.; reaction, alkaline.)

Constituents.	Grams per kilo of water	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.1650	24.40	1	200
SO_3	0.0324	4.79	1	200
CO_2	0.1800	26.61	1	200
B_2O_3	Trace	.....	..	100
As_2O_3	.....	.....	..	....
Cl	0.0947	14.00	1	200
Br	None	.....	1	100
H_2S	None	.....	..	....
O (basic)	0.0392	5.79	..	....
Fe } A }	0.0059	0.87	1	200
Ca	0.0118	1.75	1	200
Mg	0.0010	0.15	1	200
K	0.0116	1.72	1	200
Na	0.1340	19.80	1	200
Li	0.0008	0.12	1	200
	0.6764	100.00		

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
LiCl	0.0048	0.71
KCl	0.0221	3.27
NaCl	0.1320	19.51
Na_2SO_4	0.0575	8.50
$Na_2B_4O_7$	Trace	.....
$NaAsO_2$	.....	.....
Na_2CO_3	0.1463	21.63
$MgCO_3$	0.0035	0.52
$CaCO_3$	0.0295	4.36
Al_2O_3	0.0112	1.65
SiO_2	0.1650	24.40
CO_2	0.1045	15.45
	0.6764	100.00

BENCH SPRING.

(Locality, Upper Geyser Basin; date of collection, September 2, 1884; temperature, 88° C.; reaction, slightly acid.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.2400	50.88	1	40
SO_3	0.1151	24.40	1	100
CO_2	.....	.....	1	....
B_2O_3	None	.....	1	....
Cl	Trace	.....	1	100
H_2S	None	.....	..	....
O (basic)	0.0350	7.42	..	....
Fe, Al	0.0145	3.07	1	40
Ca	Trace	.....	1	40
Mg	Trace	.....	1	40
K	0.0097	2.06	1	100
Na	0.0574	12.17	1	100
Li	Trace	.....	1	100
	0.4717	100.00		

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
K_2SO_4	0.0216	4.58
Na_2SO_4	0.1772	37.57
$MgSO_4$	Trace	.....
$CaSO_4$	Trace	.....
$Al_2(SO_4)_3$	0.0066	1.40
Al_2O_3	0.0263	5.57
SiO_2	0.2400	50.88
HCl	Trace	.....
CO_2	.....	.....
	0.4717	100.00

FIREHOLE RIVER.

(Locality, above Upper Geyser Basin; date of collection, August 27, 1884; temperature, 12° C.; reaction, slightly alkaline; specific gravity, 1.00015.)

The water was filtered before bottling.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.0407	30.86	2	200
SO_3	0.0062	4.70	2	100
CO_2	0.0305	23.11	2	200
B_2O_3	Trace	.....	2	500
As_2O_3	None	.....	2	500
Cl	0.0105	7.96	2	100
H_2S	None	.....	..	....
O(basic)	0.0103	7.81	..	....
Fe	Trace	.....	2	200
Al	0.0029	2.20	2	200
Ca	0.0052	3.94	2	200
Mg	0.0011	0.83	2	200
K	0.0094	7.13	2	100
Na	0.0151	11.45	2	100
Li	Trace	.....	2	100
NH_4	0.00002	0.01	2	50
	0.13192	100.00		

Albuminoid ammonia (not in summation), 0.00010 grams per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	Trace	Trace
LiCl	Trace	Trace
KCl	0.0181	13.72
NaCl	0.0030	2.27
Na_2SO_4	0.0110	8.34
$Na_2B_4O_7$	Trace	Trace
Na_2CO_3	0.0210	15.92
$MgCO_3$	0.0038	2.88
$CaCO_3$	0.0130	9.86
Al_2O_3	0.0055	4.17
Fe_2O_3	Trace	.....
SiO_2	0.0407	30.86
CO_2	0.0158	11.98
	0.1319	100.00

YELLOWSTONE LAKE.

(Locality, near outlet; date of collection, September 18, 1884; specific gravity, 1.00014.)

The water was filtered through linen.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.0420	24.32	2	200
SO_3	0.0070	4.04	2	100
CO_2	0.0725	42.00	2	200
B_2O_3	None	.....	2	500
As_2O_3	None	.....	2	500
Cl	0.0094	5.43	2	100
H_2S	None	.....	..	...
O (basic)	0.0100	5.78	..	...
Fe	None	.....	2	200
Al	0.0021	1.21	2	200
Ca	0.0086	4.97	2	200
Mg	0.0003	0.16	2	200
K	0.0047	2.71	2	100
Na	0.0156	9.36	2	100
Li	Trace	.....	..	100
NH_4	0.00042	0.02	1	50
	0.17262	100.00		

Albuminoid ammonia (not in summation), 0.00022 grams per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0012	0.69
Li Cl	Trace	.....
K Cl	0.0090	5.21
Na Cl	0.0071	4.11
Na_2SO_4	0.0124	7.18
Na_2CO_3	0.0202	11.73
$MgCO_3$	0.0010	0.58
$CaCO_3$	0.0215	12.45
Al_2O_3	0.0040	2.32
SiO_2	0.0420	24.33
CO_2	0.0542	31.40
	0.1726	100.00

ALUM CREEK.

(Locality, at the crossing of the road; date of collection, September 19, 1884; reaction, acid; specific gravity, 1.00105.)

The water was filtered through linen before bottling.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.2180	17.83	2	200
SO_3	0.4202	34.38	2	200
CO_2	0.0075	0.61	2	200
B_2O_3	0.0057	0.47	2	500
As_2O_3	None	.....	2	500
Cl	0.2028	16.59	2	200
Br	Trace	.....	1	100
H_2S	None	.....	..	....
O (basic)	0.0840	6.87	..	....
Fe	0.0250 *a*	2.04	2	200
Al	0.0025	0.20	2	200
Ca	0.0127	1.04	2	200
Mg	0.0038	0.31	2	200
K	0.0741	6.06	2	200
Na	0.1595	13.05	2	200
Li	0.0009	0.08	2	200
NH_4	0.00106	0.09	1	50
H (in HCl)	0.0046	0.38	..	....
	1.22236	100.00		

Albuminoid ammonia (not in summation), 0.00010 gram per kilo.

a All in ferric condition.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0031	0.26
LiCl	0.0055	0.45
KCl	0.0669	5.47
KBr	Trace	.....
K_2SO_4	0.0872	7.13
Na_2SO_4	0.4924	40.29.
$MgSO_4$	0.0190	1.55
$CaSO_4$	0.0432	3.53
$Al_2(SO_4)_3$	0.0158	1.29
$Fe_2(SO_4)_3$	0.0893	7.31
SiO_2	0.2180	17.83
B_2O_3	0.0057	0.47
CO_2	0.0075	0.61
HCl	0.1688	13.81
	1.2224	100.00

CHROME SPRING.

(Locality, Crater Hill; date of collection, September 19, 1884; temperature, 92° C.; reaction, neutral; specific gravity, 1.00231.)

The water was filtered from suspended matter before analyzing and the latter was examined by itself.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.3750	13.04	2	200
SO_3	0.3618	12.59	2	100
CO_2	0.0147	0.51	2	200
B_2O_3	0.0842	2.93	2	250
As_2O_3	0.0072	0.25	2	250
Cl	1.0207	35.52	2	200
Br	.....	.....	..	....
H_2S	None *a*	.....	..	....
O (basic)	0.0801	2.78	..	....
Fe, Al	0.0043	0.14	2	200
Ca	0.0140	0.48	2	200
Mg	0.0020	0.06	2	200
K	0.1603	5.66	2	100
Na	0.7320	25.47	2	100
Li	0.0064	0.21	2	100
NH_4	0.0106	0.36	2	40
	2.8733	100.00		

a As received in the laboratory.

Albuminoid ammonia (not in summation), 0.00107 grams per kilo.

Material in suspension in a kilo of water:

SiO_2	0.4791 gram.
S	0.0757 gram.
Other insoluble matter	0.0503 gram.
	0.6051 gram.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0315	1.10
$LiCl$	0.0388	1.35
KCl	0.3062	10.66
KBr	.....	.....
$NaCl$	1.3536	47.11
Na_2SO_4	0.5804	21.46
$MgSO_4$	0.0100	0.34
$CaSO_4$	0.0476	0.45
$Na_2B_4O_7$	0.0516	1.74
Al_2O_3	0.0082	0.29
SiO_2	0.3750	13.05
B_2O_3	0.0485	1.69
As_2O_3	0.0072	0.25
CO_2	0.0147	0.51
	2.8733	100.00

A preliminary sample of 600 cm³., taken September 18, 1883, yielded, when filtered from suspended material, the following figures signifying grams of material per kilogram of water:

SiO_2, 0.2380; SO_3, 0.3516; Cl, 1.0442; Fe and Al, 0.0080;
Ca, 0.0185; Mg, 0.0024; K, 0.1438; Na, 0.6269; Li, 0.0041.

The reaction was acid.

MUSH POT SPRING.

(Locality, Pelican Creek; date of collection, October 1, 1886; temperature, 85° C.; reaction, acid; specific gravity, 1.00088.)

The water was filtered from suspended material before the analysis.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.2270		2	200
SO_3	0.5375		2	200
CO_2	0.0045		2	200
B_2O_3	0.0056		2	500
As_2O_3	None		2	500
Cl	0.0047		2	100
H_2S	None *a*		..	....
O (basic)	0.0929		..	....
Fe	Trace		2	200
Al	0.0045		2	200
Ca	0.0632		2	200
Mg	0.0214		2	200
K	0.0195		2	200
Na	0.1175		2	200
Li	None		2	200
NH_4	0.0100		2	50
H (in HCl)	0.0001		..	....
	1.1084			

a As received in the laboratory.

Albuminoid ammonia (not in summation), 0.00060 gram per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
$(NH_4)_2SO_4$ ...	0.0366	3.30
Na_2SO_4	0.3627	32.72
K_2SO_4	0.0435	3.93
$MgSO_4$.....	0.1070	9.66
$CaSO_4$	0.2149	19.39
$Al_2(SO_4)_3$.....	0.0285	2.57
$Fe_2(SO_4)_3$	Trace	.....
SiO_2.....	0.2270	20.48
B_2O_3	0.0056	0.50
SO_3	0.0733	6.61
CO_2.....	0.0045	0.41
HCl.....	0.0048	0.43
	1.1084	100.00

The water carried in suspension 0.5551 gram of insoluble matter per kilogram of water. This material dried at 104°; lost 7.33 per cent. of its weight on ignition. The partial analysis of 3.4972 grams of the ignited material resulted as follows:

	Per cent.
SiO_2	61.30
SO_3	0.63
Al_2O_3	24.24
Fe_2O_3	6.53
MnO.....	Trace
CaO	1.74
MgO.....	2.18
K_2O.....	0.57
Na_2O	0.84
	98.03

DEVIL'S INK POT.

(Locality, Mount Washburn; date of collection, July, 8, 1886; temperature, 92° C.; reaction, acid; specific gravity, 1.00221.)

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.0897	2.65	2	200
SO_3	1.9330	57.07	2	200
CO_2	0.0647	1.91	2	200
B_2O_3	0.0518	1.53	2	500
As_2O_3	None	.....	2	500
Cl	0.0058	0.17	2	200
H_2S	0.0051	0.15	2	200
O (basic)	0.3795	11.20	.	....
Fe	Trace	.....	2	200
Al	0.0037	0.11	2	200
Ca	0.0396	1.17	2	200
Mg	0.0121	0.36	2	200
K	0.0083	0.25	2	200
Na	0.0245	0.72	2	200
Li	0.0004	0.01	2	200
NH_4	0.7687	22.69	2	100
H (in HCl)	0.0002	0.01	.	....
	3.3871	100.00		

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
$(NH_4)_2SO_4$	2.8185	83.21
Li_2SO_4	0.0031	0.11
Na_2SO_4	0.0756	2.23
K_2SO_4	0.0185	0.54
$MgSO_4$	0.0605	1.78
$CaSO_4$	0.1346	3.97
$Al_2(SO_4)_3$	0.0234	0.69
SiO_2	0.0897	2.65
B_2O_3	0.0518	1.53
SO_3	0.0356	1.05
CO_2	0.0647	1.91
HCl	0.0060	0.18
H_2S	0.0051	0.15
	3.3871	100.00

SODA BUTTE SPRING.

(Locality, Soda Butte; date of collection, September 17, 1885; temperature, 18° C.; reaction, alkaline; specific gravity, 1.00138.)

The water was filtered before bottling.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.	Determinations.	Grams of water employed in each determination.
SiO_2	0.0335	1.72	2	200
SO_3	0.0614	3.15	2	200
CO_2	1.2490 *a*	64.18	2	200
B_2O_3	0.0150	0.77	2	500
As_2O_3	None	.....	2	500
Cl	0.0315	1.62	2	200
Br	None	.....	2	100
H_2S	0.0042 *b*	0.22	2	200
O (basic)	0.1618	8.32	.	....
Fe, Al	0.0069	0.36	2	200
Ca	0.2325	11.95	2	200
Mg	0.0632	3.25	2	200
K	0.0238	1.22	2	200
Na	0.0575	2.95	2	200
Li	Trace	.....	2	200
NH_4	0.0057	0.29	1	50
	1.9460	100.00		

a Cupric sulphate was used to hold back H_2S in the determination of CO_2.
b As received in the laboratory.

Albuminoid ammonia (not in summation), 0.00140 gram per kilo.

Hypothetical combination.

Constituents.	Grams per kilo of water.	Per cent. of total material in solution.
NH_4Cl	0.0169	0.87
LiCl	Trace	.....
KCl	0.0425	2.19
K_2SO_4	0.0034	0.17
Na_2SO_4	0.1062	5.46
$Na_2B_4O_7$	0.0216	1.11
Na_2CO_3	0.0419	2.15
$MgCO_3$	0.2212	11.37
$CaCO_3$	0.5813	29.87
Al_2O_3	0.0131	0.67
SiO_2	0.0335	1.72
CO_2	0.8602	44.20
H_2S	0.0042	0.22
	1.9460	100.00

am.[

c O	Fe	Al	Mn	Ba	
954	0.0049				
796	0.0012				
682	0.0051				
618	0.0069				
113	0.0006	0.0002	none.	none.	n
	0.0021				
	trace.	0.0031	trace.*h*	none.	n
185	trace.	0.0048			
053	trace.	0.0029			
175	trace.	0.0077			
386	none.	0.0027			
202	0.0081				
654	0.0002	0.0057	trace.*b*	none.	n
472	trace.	0.0021			
504	none.	0.0036			
062	none.	none.			
955	0.0018	0.0012	trace.	none.	n
	0.0009				
419	trace.	0.0009	trace.*e*	none.	n
897	0.00008	0.0027	none.	none.	n
866	trace.	0.0034			
411	trace.	0.0049			
	0.0030				
364	trace.	0.0029			
807	trace.	0.0036			
596	trace.	0.0032			
903	trace.	0.0079			
781	trace.	0.0040			
892	0.0059				
350	0.0145				
301	0.0043				
	0.0080				
340	0.0250	0.0025			
929	trace.	0.0045			
795	trace.	0.0037			
265	trace.	0.0031			
103	trace.	0.0029			
216	0.0042				
187	0.0010				
248	0.0011				
132	0.0053	0.0004			
00	none.	0.0021			

Total Na and K as chlorides, 0.9

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